BROOKLYN, N. Y., SEWAGE TREATMENT EXPERIMENTS

By

GEORGE T. HAMMOND, M. Am. Soc. C. E.

156 BERKELEY PLACE, BROOKLYN, N. Y.

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PROCEEDINGS OF THE AMERICAN SOCIETY FOR MUNICIPAL IMPROVEMENTS
NINETEEN HUNDRED AND NINETEEN

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A Brief Review of Five Year's Work

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By George T. Hammond, Surgeon (Reserve), U. S. Public Health Service, Consulting Engineer, 156 Berkeley Place, Brooklyn, N. Y.

Introduction.

Bearing in mind the brevity required in a paper intended for presentation at a Convention of this Society, it seems proper to begin it with a statement concerning the subject matter and the limits within which it is confined.

The Boro of Brooklyn has been making sewage treatment experiments for a number of years past. These experiments were interrupted and brought to a close by the war, at the beginning of 1918, when the writer left the city's service to enter the war service of the U. S. Government, as sanitary engineer to the U. S. Shipping Board, Emergency Fleet Corporation, and later to the U. S. Public Health Service.

Before leaving his duties with the city, the writer made a compilation of the data obtained from the work of the sewage treatment experiment station, at the request of Mr. E. J. Fort, chief engineer of sewers, who, as one of his last official duties before leaving the city's service to become city manager of Niagara Falls, prepared during the summer of 1918, a final report on the 26th Ward Sewage disposal, for presentation to the boro officials. The writer is informed that this report is being prepared for the printer and will soon be available to those who are interested in the details of the work, the conclusions reached, and the recommendations made for the solution of the problems for which the work was undertaken.

Soon after the work of the Experiment Station was initiated, Mr. Fort informed the writer that he had promised to have presented to this society such information in the form of papers as might be available at the time of the annual conventions. It was in accordance with his instructions that the following papers were prepared and presented by the writer:

Sewage Treatment Experimental Plant in Brooklyn, N. Y. Presented in 1914 at the Boston Convention.

Sewage Treatment by Aeration and Activation. Presented in 1916 at the Newark Convention.

To complete the series of papers on this work, the present paper was planned in 1917, and was to have been presented in

1918; but on account of the war this intention could not be realized. It has recently been revised and made considerably more brief than it was as completed in the spring of 1918; and yet apology seems due for its considerable length.

The purpose of the writer has been to treat the subject wholly as a study in sewage disposal, far removed from any official character. If it were possible to eliminate from it all reference to the special problems for which the plant was provided, this would be done, as the important matter for us in such a study is to look for the underlying principles of general application, if any such there may be. If such principles are not present, the study can be of but little if any interest. But concrete facts are necessary for illustrative data. We should, however, beware of data so local and dependent upon the concrete conditions afforded by local problems that they would not apply elsewhere. The final report on this work, when published, will go over the entire ground from the standpoint of the local problems and with all the difficulties involved in meeting local conditions. It will contain much of no interest to the engineering profession, along with many facts and data out of which interesting general principles can be laboriously extracted. With its local conclusions and recommendations, this paper will have nothing to do. But the attempt will be made herein to present some of the facts, selected carefully from that voluminous mass of material, which the writer hopes and believes will prove of interest as a basis for general discussion, thereby carrying out the original idea of Mr. Fort, as explained, when he asked the writer to prepare the series of papers of which this is the final one.

When the experiment station was authorized and constructed, and also thru its period of operation, Hon. Lewis H. Pounds was President of the Boro of Brooklyn, going out of office January 1, 1918, and Mr. E. J. Fort was Chief Engineer, from which office he resigned to become City Manager of Niagara Falls, N. Y., late in 1918. The writer was engineer of design of the Bureau of Sewers and in charge of the experiment station under Mr. Fort. Mr. W. T. Carpenter was chief chemist of the plant 1913-1917, and Mr. Murray P. Horowitz, assistant chemist. Mr. George H. Knight, assistant engineer, assisted the writer in all engineering matters, and for a considerable time represented him at the plant.

Dr. Rudolph Hering gave expert advice and revised the plans. Dr. Karl Imhoff revised the plans of the Imhoff tanks and gave much other advice. Professor Earle B. Phelps gave expert advice on sewage aeration. Much assistance was given during the work by many visiting experts.

The points that will be briefly touched on are:

(1) Some general remarks about the plant and the local conditions.

(2) A statement concerning the laboratory technic and sampling.
(3) The methods of measurement employed.
(4) The sewage, how obtained for the experiments, its quantity per capita, and most important characteristics.
(5) Some remarks on the operation of Imhoff tanks, trickling filters, and settling tanks, sludge digestion and sludge drying, giving results obtained in very short retention periods, and by very rapid operation of the filter beds.
(6) Some studies on the operation of Riensch-Wurl screens and the application of screened sewage to trickling filters.

A Brief Review of the Work

Sewage investigations were commenced at this station in 1910 by Professor Earle B. Phelps, and General (then Colonel) William M. Black, Corps of Engineers U. S. A. Their report on the aeration treatment of sewage, now a valued classic in sanitation literature, was presented in 1911. The studies were continued by the Bureau of Sewers under Mr. E. J. Fort, assisted by the writer, and in 1912 an extensive experimental plant was authorized. At the same time a new sewage disposal plant was provided for by the Board of Estimate—the design to await the results of experimental study. Local conditions were given careful study, and all American sewage disposal plants of note were visited by Mr. Fort and the writer.

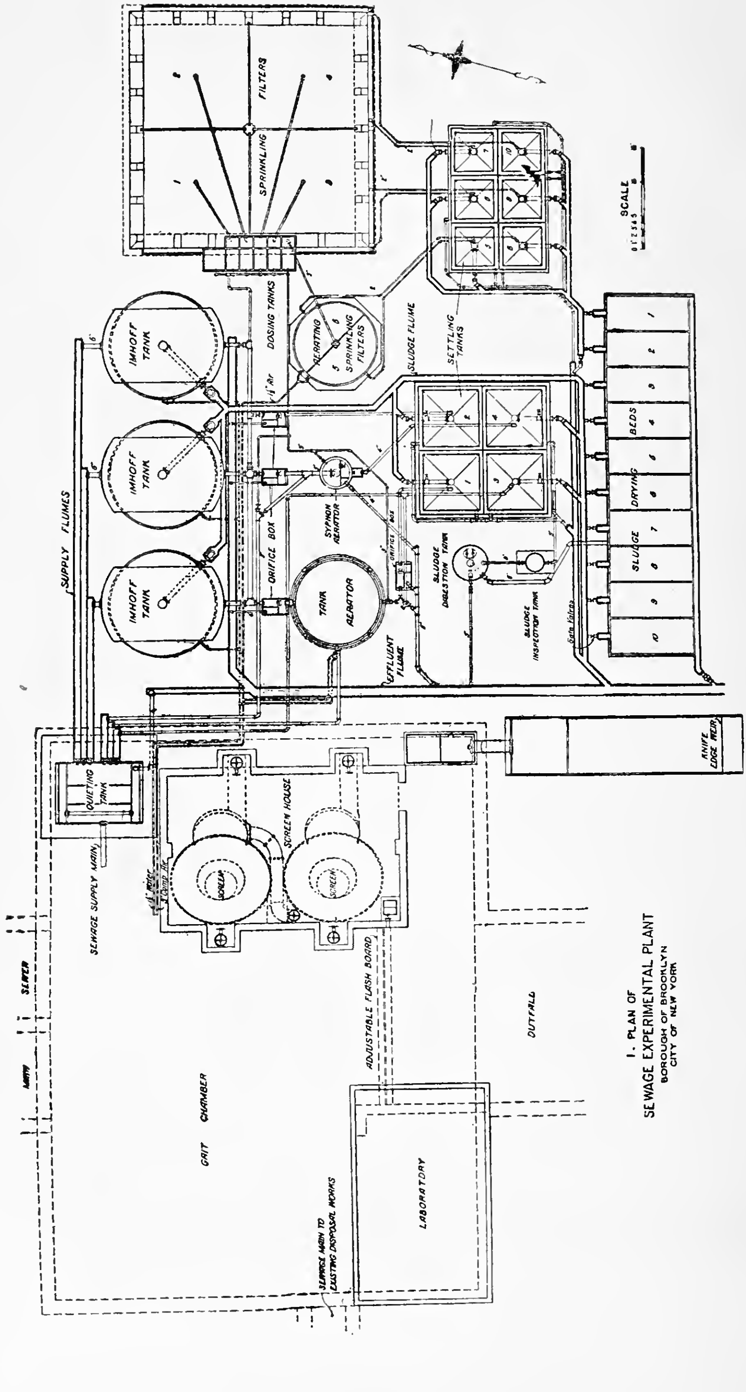
During the spring and summer of 1912, Mr. Fort and the writer, in company with Dr. Rudolph Hering, visited the more important sewage disposal plants in Great Britain and on the European continent,—taking in all of the principal cities in England, Germany, France, Switzerland, etc.—gathering data for the design of the experimental units and also for the permanent plant.

In 1913 the experimental units and laboratory were completed, except the screens, which were not placed until 1916. Operation of the three Imhoff tanks, plans of which had been revised and approved by Dr. Karl Imhoff himself, was started in 1913, and at the same time all of the trickling filters and aeration experiments. This work was continued through 1914 and 1915, and indeed until the close down of the plant in January, 1918.

Sewage aeration experiments were undertaken concerning activated sludge from 1915 to 1918.

The Riensch-Wurl screens were installed in 1916, and experiments with them continued to 1918.

There was much other experimental work done on various other methods of sewage treatment, and on variations proposed in the standard methods, but this work may be considered as relatively unimportant, and led to no conclusions worth stating here.



1. PLAN OF SEWAGE EXPERIMENTAL PLANT
BOROUGH OF BROOKLYN
CITY OF NEW YORK

It may be observed that every kind of an experimental unit designed was itself an experiment. It was only by installing such a plant that the actual conditions under which it would be operated could be fully discovered. It was anticipated by the writer that as much could be learned from the troubles and limitations discovered in operation, as from the successful performance of the different units. Long and careful study, and many changes in experimental units, are required in order to obtain dependable results in these studies, and a careful recognition of existing conditions and circumstances under which a plant shall operate, and the adaptation of the plant to these conditions, is essential to the success of these investigations.

The experiment station consisted of a laboratory for the chemical and bacteriological work connected with the study of sewage, and a sewage treatment experimental plant. The size of each of the various units of the plant was made large enough to permit operation on a scale sufficiently great to take it out of the class of a mere laboratory test. All of the work was carried out on such a scale that each experiment was made under conditions designed to approach actual sewage-disposal-plant conditions.

The plant included three Imhoff tanks of different depths, but with other corresponding dimensions equal; six trickling filter beds, two of which were designed for discharging compressed air within the mass of the stone medium; various tanks and apparatus for the investigation of sewage treatment by forced aeration; secondary settling tanks for the trickling filters, and for the sewage treated by aeration; a plain settling tank for crude sewage in connection with an airtight sludge digestion tank, which received the settled matters and sludge from the settling tank, being

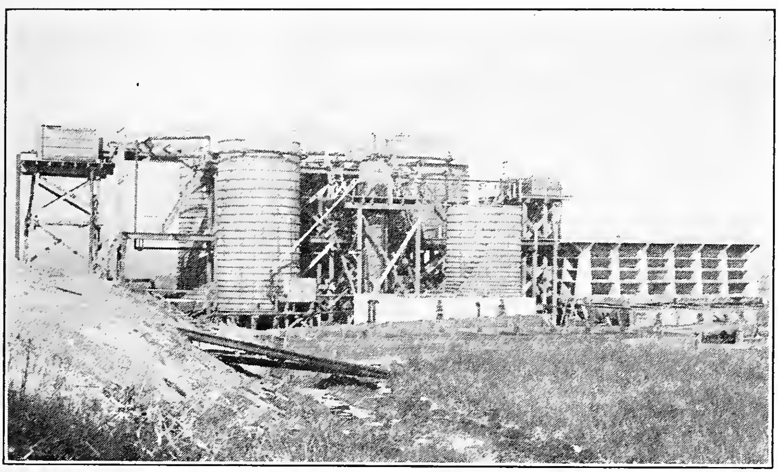


Fig. 2. View of Plant When Put in Service, Oct. 1, 1913.

in effect the two essential portions of an Imhoff tank separated; ten sludge-drying beds, and various units for experimenting with fine-screened sewage, and for drying sludge.

The mechanical plant consisted of steam-actuated sewage pumps and an air compressor; with attachments and appliances for measuring volumes of air delivered.

The pumps that furnished the sewage for the experiments were located within the existing sewage disposal works buildings, and steam was obtained from the boilers of that plant. There were two sewage pumps, both of direct-acting piston type, so installed that either one could be cut out and cleaned or repaired without stopping the other. The larger pump had a capacity of 1,200,000 gallons per day, and the smaller 650,000 gallons.

The compressor installed was a duplex crank and fly wheel machine; automatic in starting, stopping and speed; with a displacement capacity of 228 cubic feet of air per minute at not exceeding 210 r.p.m. for 30 lb. air pressure and with 100 lbs. of steam at the throttle. It was equipped with a combination speed and pressure governor, arranged to bring the machine to a dead stop if no air was demanded, and to start up automatically upon drop of the pressure.

The first thing determined, in making the design, was the required elevation of the surfaces of the sewage in each unit of the plant. This determined, the unit was designed to comply with it.

The low elevation of the ground at the site, but a few inches above ordinary high tide—a tidal marsh, in fact—necessitated the placing of the experimental units above the reach of the highest tide, and pumping the sewage up to such a level that a gravity flow could be obtained for every unit of the plant.

The datum line was at mean high water and the surface of the sludge beds was placed at an elevation of 2.67 feet above this datum. All of the other units of the plant were given such elevations above this as their operation required. Every unit was provided with a measuring device, for the determination of the flow, usually consisting of an adjustable, calibrated orifice above which a constant head was maintained by a system of overflow weirs. Surplus flow wasted back to the main sewer. There was always a considerable surplus flow, so as to keep a good velocity in passages.

For measuring compressed air, Venturi meters were provided. The accuracy of all the measuring devices was carefully tested in place.

The construction of the plant, for the most part above the surface of the ground, afforded opportunity for studying the flow of sludges of different kinds, Imhoff especially, which could not as easily have been studied otherwise; also, the effect of cold

weather on exposed sprinkling filter beds; the danger of freezing of the various channels carrying sewage, and the proper method of protecting and operating the same. These studies were of much interest from the engineer's standpoint, in view of the projected construction of a trickling filter plant on concrete pile foundations over an extensive marshland.

ADJUSTABLE ORIFICE

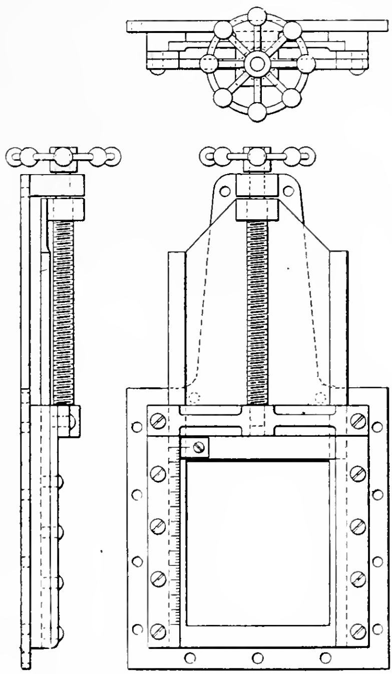


Fig. 3.

Laboratory Control and Sampling

The laboratory was erected as part of the experiment station, and supplied with heat and power from the plant of the existing sewage treatment works. It was provided with the usual apparatus for sewage investigations and for the filing and classifying of results. The laboratory work conformed to standard practice. The standard methods of the American Public Health Association were followed. The analytical work and record keeping were organized by Mr. W. T. Carpenter, Chief Chemist, and the methods introduced by him were followed thruout the entire period.

Samples having to do with the "oxygen balance" of the sewage, and various effluents, are from their nature, incapable of being composited. Effort was therefore made to take them at such a time of day that the sewage would be most likely to be of average quality. The monthly averages from which conclusions were drawn were averages of ten or more samples.

Samples for the determination of such constituents as are properly made on composites were collected as follows:

A full set of half-pint samples was taken every four hours, midnight to midnight, and put into bottles with chloroform. These bottles, being the primary composites, were renewed daily, and a pint portion taken to form the secondary composites for analysis. The analyses of the composites were never made less frequently than five times monthly, and ten times for all the more variable conditions of sewage flow. Monthly averages were determined by the composition of about 250 individual portions.

In order that there may be no misunderstanding as to the meaning of certain terms used in this paper, which are not always given the same definition, the following explanation, prepared by Mr. Carpenter, is appended:

Settling Matter is the *volume* of matter, solid and water content, which will settle to the bottom of an Imhoff settling cone, and is expressed in cubic centimeters per liter.

The time period used in all of these determinations was two hours. After an hour's settling the cones were rolled between the hands a few times, to send to the bottom such of the solids as adhered to the sloping sides.

By *Total Suspended Solids* is meant the gravimetric amount of dry material which will be retained upon the asbestos mat in a Gooch crucible, after filtration with suction. Its weight is expressed in parts per million parts of the sewage from which it is taken.

By *Volatile Suspended Solids* is meant that portion of the dry material in the Total Suspended Solids which is lost by incineration at cherry red heat, in a muffle furnace. It is expressed in weight in parts per million, and by per cent. of the Total Suspended Solids.

It is doubtless more than the organic matter, but the difference is not readily determinable, and probably constant within very narrow limits, and unimportant, as the figures are only of interest in making comparisons. During the first three years the character of the suspended solids was analyzed closely to determine what portion of the solids was settleable, and what portion non-settleable, or colloidal. The Gooch-crucible method was used. The total suspended solids were determined on an unsettled sample, and the colloidal solids on a sample siphoned from the upper

portion of the contents of an Imhoff cone after two hours' sedimentation. The latter are called *Colloidal Suspended Solids,* though they undoubtedly contain a minute and scarcely appreciable amount of material capable of settling in longer periods of time. The *Settling Suspended Solids* are the difference between the two.

Oxygen Consumed was determined in accordance with the 1913 Standard Methods of the American Public Health Association, using a 30-minute digestion period, the heating being done in an Arnold steam sterilizer. The determinations were made on raw and on paper-filtered samples of sewage.

Nitrogen as Free Ammonia was obtained by direct nesslerization.

Organic Nitrogen was determined colormetrically by the Kjeldahl process after direct nesslerization.

Nitrogen as Nitrites was determined according to "Standard Methods".

Nitrogen as Nitrates was determined by the phenol-sulphonic method.

This procedure was adopted after experimenting upon the brucine and the narcotine methods. The reduction method was considered too time-consuming to be justified with the force available. Care was used at all times to insure the evaporation of the last drops of the sample in the air, instead of on the steam bath, in order to avoid loss of nitrogen in consequence of a high chlorine content. This determination is most significant where oxidized effluents are concerned, and the nitrate figures are to be interpreted as being at least the recorded values. The determination of both nitrite and nitrate nitrogen was preceded by clarification of the samples by alum.

Temperature was recorded in degrees centigrade.

Dissolved Oxygen was determined by the use of the Hale and Melia modification of the Winkler process.

Relative Stability was determined in bottles containing 250 c.c. of the sample, when full, which were stoppered with corks, after adding ½ c.c. of a 0.05 per cent. aqueous solution of methylene blue. The bottles were incubated at the laboratory room temperature, and the time of decolorization noted. The relative stability number, or value in terms of the per cent. stable, was obtained from the table in Standard Methods, A. P. H. A.

Oxygen Demand (Biochemical), or more simply *Demand,* is the amount of dissolved oxygen in parts per million parts of the sewage, which sample of sewage, or treated effluent, will take up from thoroly aerated clean water, when incubated in a glass-stoppered bottle, at room or standard temperature for five days. It is assumed that it measures the amount of dilution necessary to prevent a nuisance when sewage is discharged into a body of

water, and also to approximate the condition of a stream, if re-aeration did not take place. The determination was made according to Standard Methods, A. P. H. A.

Local Conditions

The Twenty-sixth Ward of the boro of Brooklyn constitutes the extreme easterly portion of the boro. The population (1918) was estimated from police and school records to be 220,000. The surface slopes from high lands along the northerly boundary, at first with short but sharp grades, into a gently sloping plain, which constitutes about 85 per cent. of the area. This has resulted in the design of a sewerage system with very flat grades. The drainage and sewage are discharged into the waters of Jamaica Bay.

The hourly rate of flow in dry weather, based upon data determined by weir measurements in the outfall, varies at present (1918) from about 18,000,000 to 27,000,000 gallons per day. The storm flow from the area at present provided with sewers ranges up to 1,000 cubic feet per second, altho the ordinary storm does not give more than 300 to 500 cubic feet per second. The dry weather flow is mainly of a domestic character. The suspended matters change widely in quantity at different seasons, and at different hours of the day. The increase of population occupying the drainage area is notable and of interest in showing how rapidly New York suburban districts become urban, as may be seen from Table I.

The sewerage system was mainly installed between the years 1890 and 1896 and includes a chemical-precipitation sewage-treatment plant, designed in 1888 and intended to take care of a maximum population of 35,000, which, at the time, was considered ample provision for the future. This plant was completed in 1896, when the population had already reached about 60,000. It, therefore, was inadequate from the beginning of its operation, altho for several years it rendered fairly good service.

The sewage passing thru the plant flows thru fixed screens and narrow settling tanks, with considerably velocity, to a central well, from which it is pumped into the outfall sewer. The pumps have a nominal capacity of about 20,000,000 gallons per day, but on account of depreciation are incapable of pumping more than half this quantity at present.

The twin outlet sewers, which are combined sewers with very flat grades, terminate at the location of the plant in a silt basin, which, in dry weather, serves as a grit chamber for the sanitary sewage. This basin, which is covered, is 80 ft. by 60 ft. in plan, and is 9 ft. deep, acts as a trap to divert the sewage in dry weather into the treatment plant. The basin is provided with a high level overflow for storm water, and the line of the sewer is

continued by means of an outfall flume, beginning at the high-level overflow mentioned and extending from the basin to Jamaica Bay. The outfall flume is a single channel section, 26 feet wide; its invert grade begins at the basin 3.40 feet above the invert grades of the twin sewers and, as it is inadequate in storms of much severity, it backs up the flow in the twin sewers and causes flooding. In dry weather the sewage which cannot be taken care of by the existing treatment plant overflows thru the storm outlet and discharges into the bay without treatment.

A passageway, 48 inches in diameter, is provided from the grit chamber to the existing treatment plant, with the invert at the floor elevation of the grit chamber, for carrying the dry-weather flow into the plant, where, after receiving its charge of lime, and having passed thru the screens and tanks, it flows into the central pump well. From the well the treated sewage is pumped against an average head of 20 feet into the outfall flume at a point about 100 feet downstream from the silt basin. During storms the by-pass valves are closed and the entire flow discharges directly from the grit chamber thru the outfall flume to the bay.

During a moderate rainfall the volume of flow carried off by the sewers is about ten times the ordinary volume in dry weather. To make matters worse, the existing sewers are not of modern design and do not adapt themselves well to this double service and are usually too small for present conditions of storm service. They are, however, much too large for efficient operation in dry weather, and this is especially the case in the outfall sewers, which on account of low street grades and lack of sufficient cover, are flat and broad, and blanketed by the tide at their outlet.

This condition results in making the sewers elongated settling tanks as they approach the outlet of the system, and the dry weather flow passes thru them with progressively falling velocity from the lateral sewers to the outlet; they are all, therefore, sewers of deposit in dry weather and would cause great trouble from smells as well as from clogging with banks of sedimented solids, if it were not that the periodical storms flush them out, carrying the matters that have collected in dry weather with the rush of the flood wave into Jamaica Bay. The first part of the storm flow is, therefore, exceedingly foul, much more so than the ordinary dry-weather flow.

Measurement of Sewage.

The measurement of the total flow of sewage discharged by the main outfall sewer in dry weather, and its hourly and daily variations was obtained by means of a knife-edge weir installed in the outfall flume. It was sharp crested with end contractions suppressed. The crest length was 25.84 ft. and the height 2.17

ft. The horizontal knife-edge was installed by means of a wye level; the adjustments were made from slotted bolt holes, and finally by filing off very small irregularities.

The device for recording the heads of flow on the weir consisted of an automatic water stage register, with a specially designed apparatus for magnifying the gage heights placed in a Bazin pit installed just outside of the channel, and 16 feet up stream from the crest of the weir. The pit was connected with the flume by means of an iron pipe 3 feet long, laid on the floor, and perpendicular to the side of the approach channel to the weir.

The zero of the register was determined by means of a hook gage and wye level. The correction for slack motion of the register was determined by hook gage to be ½ of 1 per cent.

A similar knife-edge weir, with end contractions suppressed, with a crest 8 feet in horizontal length, was used to measure effluent from the Riensch-Wurl Screens.

This weir was placed in a specially prepared flume located parallel to and alongside of the main outfall flume, the flow reentering the main flume several hundred feet below the experiment station.

The details of this weir are similar to those of the larger weir.

In computing the discharge over these weirs the formulae of Bazin, Fteley and Stearns, Francis, and Hamilton Smith, were employed. The formula of Bazin was selected as probably the most applicable to the kind of weir used under the observed conditions. Taking Bazin at 100 per cent we have the following comparative values:

Bazin	100 %
Fteley and Stearns	96.2%
Francis	95.6%
Hamilton Smith	95. %

Calibrated Orifices.—For the measurement of sewage delivered to the various units of the experimental plant, calibrated orifices, discharging under a constant head, were selected as the most satisfactory, as errors would be less than would be the case with weirs. In the use of such orifices, the calibration could be checked experimentally with the apparatus in place by discharging into a measuring tank, or into the unit which the given orifice was designed to supply with sewage. The latter was found to be a satisfactory method. The calibration was performed against the tank which was to be controlled by the orifice, and the head was held by allowing a slight excess to waste over a weir above the orifice.

The orifices originally designed were made of bronze; they were adjustable, and provided with scales for setting the size of the opening for various rates of discharge. To measure small

rates of flow, orifices were made in copper plate in the machine shop of the treatment plant, which gave entire satisfaction.

The accurate measurement of sewage is at best a difficult matter. The suspended material will affect almost any form of apparatus used for the purpose; orifices not excepted. However, with regular and frequent cleaning, the types of orifices adopted were satisfactory and gave results that were well within the accuracy of the chemical tests and their interpretation.

Measurement of Compressed Air.—On account of the volume of air to be metered, and the pressure, no form of available gas meter was found fully to answer the requirements; therefore, several forms of Venturi meters were studied and a meter was developed, which worked very well. The contract to make and install these meters, and to test them in place, was awarded to Messrs. Wallace & Tiernan, of New York.

The quantity of compressed air that would be required in sewage aeration was unknown, at the beginning of the experiments, and it was therefore necessary to provide for a wide range in measuring capacity. This was accomplished by having several interchangeable throats of different sizes for each Venturi meter, and a specific manometer scale for each throat.

Three sets of meters were obtained, each of which was standardized as to measuring capacity, against an operating head of 40 lbs. air pressure, and calibration scales were worked out for pressures from a minimum of 5 lb. to a maximum of 40 lb. per

AIR VENTURI METER

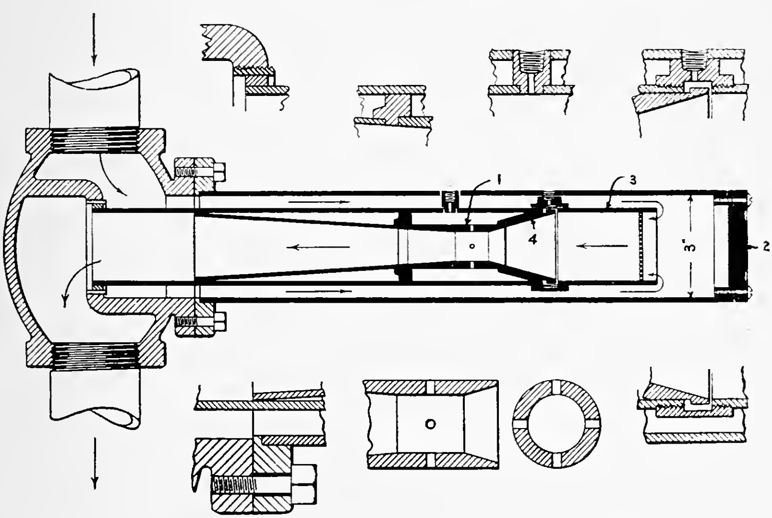


Fig. 4.

square inch, in order that by exchanging scales any pressure within these limits might be used. The measuring capacity of each set of meters under the 40 lb. pressure standard was as follows:

Set No. 1 capacity 20 to 150 cu. ft. per minute.
Set No. 2 capacity 5 to 20 cu. ft. per minute.
Set No. 3 capacity 1 to 30 cu. ft. per minute.

The meters were each assembled in cylinders of the same size, so that any one of them could be installed in the body of an ordinary 3-inch check valve, put in the air line. There were three Venturi tubes complete, supplied for each meter; two of these were of small capacity, of which each had two interchangeable throats, while the third was larger and had but one throat.

Referring to the drawing, Fig. 4, air passes along the line indicated by the arrows, thru the throat and out thru the air line.

The manometer used was of special design. The cross section of the oil reservoir was made many times greater than that of the manometer tube, so that the zero point was practically unaffected thru the range of the scale. The upper end of the manometer tube was connected with the Venturi throat chamber, and had an upper reservoir interposed, of slightly greater capacity than that of the lower reservoir. This was provided to prevent the blowing of any oil into the pipe line by sudden rushes of air.

The calibration of these meters was an interesting problem.

CALIBRATION BOX

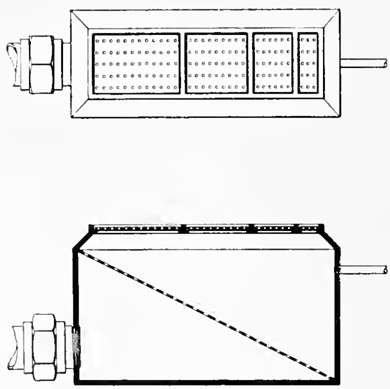


Fig. 5.

On account of the quantity of air it was impracticable to use a gasometer. Therefore a calibrating box, consisting of a special multiple-orifice box, was designed to receive and measure the air

passing thru the meter. This box is shown in Fig. 5. The top of the box was a metal plate having in all 150 orifices, each exactly equal in size and all made with the same die, and equally spaced. A cover plate was provided, so designed that any number of orifices from 1 to 150 might be left open. The orifices were each computed and made of proper size to discharge 1 cu. ft. of air per minute under a head of 10 inches of water pressure. A perforated metal screen was placed diagonally across the box to prevent eddy currents. Preliminary readings were made for rating this work, with a small gasometer, to determine the air flows from different orifices and from different groups of orifices to see if there was any variation because of location or number of those discharging. The flows were found to agree within 1/5 of 1 per cent.

In calibrating a meter, the box was connected with the air line thru the meter, and a certain number of orifices uncovered on the top of the box, a stop-valve being opened until the desired head was shown on the box manometer.

Knowing the discharge for this number of orifices, and the corresponding pressure, it was a simple matter to mark on the Venturi manometer scale the flow corresponding to the height of the liquid.

After having determined several of these points, the scale was graduated in cubic feet.

Distribution Control.—In order that the sewage coming from the pumps might pass by gravity to every unit, and that the impulse imparted by the pump might be removed, a quieting and distributing tank was provided, thru which the entire plant could be supplied except the R. W. fine screens.

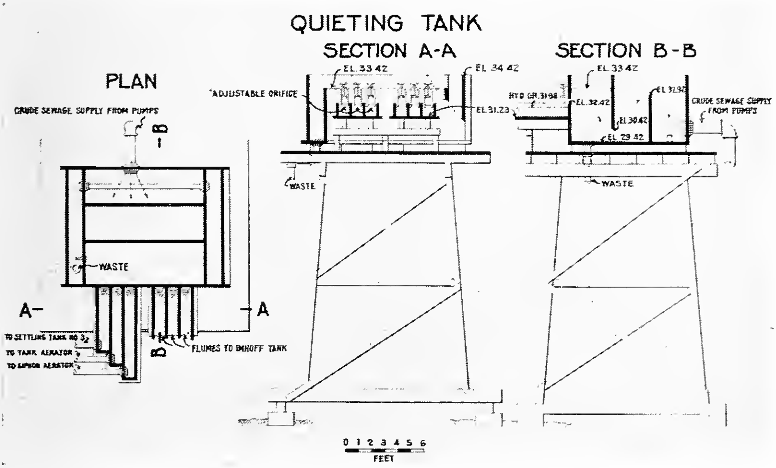


Fig. 6.

Quieting Tank.—The quieting tank (Fig. 6) was designed to maintain a constant head in the supply, at elevation 33.42 feet. A platform around the tank was provided for convenient inspection and operation, and connected by means of a bridge with the tops, or "decks", of the three Imhoff tanks.

Obtaining Sewage for the Experiments

When the work was commenced on the design of the experimental plant in 1912, one of the first problems presented was how to obtain sewage from the large sewers of fair average strength and condition.

The following local conditions prevailed: The passages of the large twin sewer, each 12 ft. 6 in. wide by 9 ft. high, entered the grit chamber with their inverts at — 2.40, datum being mean high water. The surface of the flow of sewage in the sewers and grit chamber at this point averaged about elevation + 2.37 for dry-weather flow sewage, but was subject to changes of level during the day between elevation + 1.75 and + 3.00.

The surface velocity of the sewage as it entered the grit chamber ranged from about half a foot to more than a foot per second, under different conditions of flow.

The sewers and grit chamber acted to some extent as a sedimentation tank, sewage solids, as well as grit, being deposited at all times during dry weather in greater or less quantities. The inverts of the larger sewers of the Twenty-sixth Ward are shallow and wide, and the grades too flat, as a rule, to afford sufficient velocity of flow to prevent considerable of the suspended solids in the sewage from settling and forming deposits, which during storms are picked up by the high velocity of flow and flushed out into Jamaica Bay. During the first rush of the storm the discharge is even more foul than the ordinary discharge of sewage in dry weather. Following this, however, after the flushing out of these deposits has been completed, the storm flow rapidly improves in quality and soon becomes mere dirty water, which is incapable of causing a nuisance, and does not require treatment.

The by-pass, provided to carry the dry-weather flow from the grit chamber of the treatment plant, is given off from the lower portion of the chamber, the bottom of which agrees with the invert of the by-pass, and is elevation — 3.00. Since the by-pass is 48 in. in diameter, the crown of its arch is elevation + 1.00. It enters the treatment plant with its gates at invert elevation — 3.50, which is above the water line in the receiving tanks of the plant, so that sewage enters with a free flow.

The name "grit or silt chamber" is really a misnomer, for most of the grit and silt settles from the sewage in the large sewers before the chamber is reached.

All of the storm flow and about two-thirds of the dry weather flow, which cannot be admitted to the treatment plant, discharges from the grit chamber at elevation +1.00 into the outfall flume which runs 3,230 feet to the bay.

It was observed that the sewage passing into the treatment plant, thru the by-pass, gave a more consistent average proportion of the total and suspended solids, than that which passed into the bay thru the outfall sewer, which, on the average, was a weaker sewage, altho at times it was much stronger, and carried more floating matter, as well as settleable solids, but was subject to greater variation in suspensa, as well as volume of flow. These conditions indicated that the most appropriate sewage for study in the experimental work was that entering the treatment plant, as near the outlet end of the by-pass as practicable. For, altho this sewage was slightly stronger than the average of the entire flow, this would give results on the safe side; while the other flow was weaker than the average, and would, therefore, give more fallacious results.

TABLE I

Population of the 26th Ward of Brooklyn, N. Y.

Year	Increase of Population, 26th Ward, Brooklyn. Population to nearest 1,000
1880	13,000
1890	30,000
1900	66,000
1905	94,000
1910	178,000
1914	200,000
1918	220,000

TABLE II

Daily and Hourly Flow of Sewage

DRY-WEATHER FLOW OF SEWAGE CONTRIBUTED BY 220,000 PEOPLE REACHING THE OUTLET IN HENDRIX STREET, BASED UPON DATA OBTAINED BY WEIR MEASUREMENTS, REDUCED TO HOURLY PERCENTAGE OF FLOW PER CAPITA: MAXIMUM DAILY RATE PER CAPITA 121 *gallons*. MINIMUM RATE 81 GALLONS. PREPARED FOR JANUARY 1, 1918.

Hour	Pct. of max. flow	Cu. ft. per sec.	Rate in M.g.d.
12 a. m.	78.5	32.49	21
1 a. m.	74.4	30.92	20
2 a. m.	71.	29.40	19
3 a. m.	67.8	28.62	18.5
4 a. m.	67.	27.85	18
5 a. m. min.	66.1	27.07	17.6
6 a. m.	67.8	27.85	18
7 a. m.	72.8	30.17	19.5
8 a. m.	81.	33.65	21.75

Hour	Pct. of max. flow	Cu. ft. per sec.	Rate in M. g. d.
9 a. m.	87.6	36.36	23.5
10 a. m.	91.7	37.90	24.5
11 a. m.	93.4	38.68	25
12 p. m.	96.7	40.23	26
1 p. m.	99.2	41.00	26.5
2 p. m.	99.2	41.00	26.5
3 p. m. max.	100.	41.29	26.62
4 p. m.	97.5	40.61	26.25
5 p. m.	96.9	39.84	25.75
6 p. m.	94.2	39.06	25.25
7 p. m.	89.2	37.13	24
8 p. m.	85.9	35.59	23
9 p. m.	84.3	34.81	22.5
10 p. m.	84.3	34.81	22.5
11 p. m.	82.6	34.42	22.25
12 p. m.	78.5	32.49	21

The weekly cycle of daily and hourly per capita flow of sewage is shown by Table III, as well as the quantity of flow for each day of the week. The figures are averages.

TABLE III

Per Capita Flow of Sewage in Gallons for Every Hour of the Day and Week

1914-1915

Hour	Sun. gal.	Mon. gal.	Tues. gal.	Wed. gal.	Thurs. gal.	Fri. gal.	Sat. gal.
5 a .m.	3.3	3.4	3.6	3.2	3.4	3.6	3.0
6 a. m.	3.3	3.6	3.8	3.3	3.5	3.6	3.2
7 a. m.	3.4	3.8	4.1	3.6	3.6	3.6	3.5
8 a. m.	3.9	4.2	4.4	4.3	4.2	4.1	3.9
9 a. m.	4.5	4.8	4.8	4.5	4.8	4.5	4.3
10 a. m.	4.8	5.8	5.0	4.6	5.0	4.7	4.4
11 a. m.	5.0	5.1	4.8	4.7	5.0	5.0	4.4
12 a. m.	5.1	5.4	5.0	4.7	5.0	5.0	4.7
1 p. m.	5.0	5.5	5.0	4.7	5.1	5.0	4.8
2 p. m.	4.8	5.2	4.8	4.8	5.3	5.1	5.0
3 p. m.	4.8	5.1	5.1	4.8	5.3	5.2	4.0
4 p. m.	4.7	4.8	5.1	4.8	5.0	4.4	4.8
5 p. m.	4.5	4.7	5.0	4.7	5.0	4.3	4.7
6 p. m.	4.4	4.6	4.7	4.6	4.8	4.3	4.5
7 p. m.	4.2	4.5	4.5	4.6	4.7	4.2	4.4
8 p. m.	4.2	4.5	4.5	4.4	4.5	4.2	4.4
9 p. m.	4.1	4.5	4.4	4.4	4.1	4.1	4.2
10 p. m.	4.1	4.4	4.3	4.4	4.4	4.1	4.1
11 p. m.	4.1	4.3	4.2	4.3	4.3	4.1	3.8
12 p. m.	3.9	4.2	3.9	3.9	4.2	3.9	3.7
1 a. m.	3.7	3.9	3.9	3.7	3.7	3.9	3.5
2 a. m.	3.5	3.6	3.8	3.5	3.5	3.8	3.5
3 a. m.	3.4	3.5	3.7	3.3	3.3	3.6	3.3
4 a. m.	3.3	3.4	3.6	3.2	3.3	3.6	3.1
Totals	100.0	106.0	106.0	101.0	105.0	101.9	97.8

Mean flow for week, 102.5 gallons per capita.

The Storm Water Sewage

The effect of storms on the quality of the sewage was always greatly to increase the matters in suspension during the first period of the storm. Where the storm was of short duration, this increase continued thruout the storm, but if the duration was continued over several hours, a marked improvement took place in the flow.

This condition, as already mentioned, was probably due to the large size of the main sewers, which are on the combined plan, and have very flat grades thru much of their extent, and shallow inverts, into which considerable settling matter falls in dry weather, being flushed out by the flood wave of the storm.

Two storms, of ordinary severity such as frequently occur at this place, and a rather high rate of precipitation, may be given here in illustration of the phenomena attending upon the flow of storm sewage, during the usual summer shower.

The first storm referred to ("A" in Table IV) took place on May 27, 1914. The total rainfall recorded was .15 inches, of which .10 fell in the first half hour. The second, ("B" in the table) occurred on August 21 of the same year. The rainfall, according to the gage, was 1.0 inch in all, 0.9 inch falling in the first half-hour.

The following phenomena were common to both storms. After a lapse of from twenty-five minutes to an hour from the beginning of rainfall, the sewage became very foul, as shown by the remarkable leap in suspended solids. The persistence of this abnormal content was only about an hour in the heavier storm, and about two hours in the lighter one. The presence of considerable quantity of gritty street washings is indicated by a marked drop in the percentage of volatile matter in the suspensa. In the storm of May 27, this drop took place some time later than the time of maximum suspended matter, but in the storm of August 21, the street wash appeared to come coincidently with the outflush of sludge from the inverts of the trunk sewers. The accompanying Table IV gives the figures:

TABLE IV

Hrs. after beginning of rain	Settling Matter c.c.l.		Suspended Solids Total p.p.m.		Suspended Solids Volatile %		Dissolved Oxygen p.p.m.	
	A	B	A	B	A	B	A	B
Date	5-27	8-21	5-27	8-21	5-27	8-21	5-27	8-21
0	2.7	3.2	226	252	74	76	.6	.7
¼	1.5	3.0	208	254	78	75	.5	.6
½	2.1	6.2	248	412	73	77	.4	0
¾	2.5	16.5	250	2250	72	40	.4	0
1	29.0	12.8	1880	1976	72	41	0	0
1½	2.7	4.0	588	820	35	27	0	0
2	5.4	2.5	1126	480	28	30	.1	1.9
2½	5.5	2.6	1096	480	29	38	.6	1.1
3	4.2	......	494	....	39	....	.7	....
4	2.2	......	204	....	47	....	2.5	....
5	.9	......	118	....	63	....	1.9	....
6	.5	......	84	....	52	....	2.4	....

The most important characteristics of the dry-weather flow sewage are exhibited by Table V, which for the data given covers the period of the experimental work of the station, upon which the report is based. It should be noted that the figures given are averages, and as such do not show either extreme of the conditions.

TABLE V

General Characteristics of 26th Ward sewage

From Monthly Averages for the Period of Experiments

Month	Temp. °C	Diss. p.p.m.	Oxygen % sat.	Suspended Solids Total p.p.m.	Suspended Solids Volatile p.p.m.	Suspended Solids Non-Vol. p.p.m.	Cone c.c.l.	Oxygen Demand Biochem p.p.m.
Jan.	11.0	4.5	41	175	140	35	2.1	209
Feb.	10.0	4.5	40	172	134	38	2.0	262
March	11.6	3.6	33	192	142	50	1.8	220
April	14.7	2.8	27	162	124	38	1.7	195
May	18.2	1.9	20	178	136	42	1.9	213
June	20.9	1.2	13	153	118	35	1.6	250
July	26.0	0.8	10	163	118	45	1.7	202
Aug.	23.8	0.6	7	146	112	34	1.7	203
Sept.	22.1	0.5	6	168	136	32	2.1	237
Oct.	17.5	1.9	20	146	108	38	1.8	205
Nov.	13.9	3.8	37	160	132	28	1.7	254
Dec.	10.8	3.8	34	203	155	48	2.6	223
Average	16.7	....	....	168	129	39	1.9	223
Seasonal variations by averages								
Dec.-Mar	10.8	4.1	37	186	143	43	2.1	228
Apr.-June	18.0	2.0	21	164	126	38	1.7	219
July-Sept.	24.0	0.6	7	159	122	37	1.8	214
Oct.-Nov.	16.0	2.9	29	153	120	33	1.8	229

TABLE VI

Showing Oxygen Relations of Sewage for One Year

Oxygen Consumed in 30 Minutes Digestion

Month & Year	Susp'd Solids Total p.p.m.	Susp'd Solids Volume p.p.m.	Nitrogen as Nitrites p.p.m.	Nitrogen as Nitrates p.p.m.	Oxygen Consumed Unfiltered p.p.m.	Oxygen Consumed Filtered p.p.m.	Diss. Oxygen* p.p.m.	Diss. Oxygen* % sat.	Temp. C °C
1914									
April	126	98	.67	.31	53	40	5.0	48	13.7
May	164	129	.21	.09	60	41	2.2	22	18.3
June	125	96	.09	.02	48	35	1.5	17	21.1
July	152	97	.37	.01	56	44	1.8	21	22.3
Aug.	128	101	.21	.05	53	38	1.2	14	23.9
Sept.	164	130	.07	.05	58	37	1.2	14	21.4
Oct.	127	101	.13	.07	51	35	2.2	24	19.4
Nov.	158	126	.28	.14	51	39	1.9	19	15.9
Dec.	201	155	.37	.13	71	44	2.0	18	12.0
1915									
Jan.	175	142	.33	.13	74	48	2.6	26	11.6
Feb.	219	168	.13	.13	82	52	2.5	25	11.0
March	203	155	.31	.16	75	50	1.4	13	13.3

* Comparative dissolved oxygen values during an average day, by two-hour periods. Lowest hourly value assumed to equal 1,000. Twenty-sixth Ward Sewage:

Midnight	1.100	2 p. m.	1.182
2 a. m.	1.100	4 p. m.	1.341
4 a. m.	1.205	6 p. m.	1.000 min.
6 a. m.	1.300	8 p. m.	1.100
8 a. m.	1.545 max.	10 p. m.	1.114
10 a. m.	1.478	Midnight	1.100
Noon	1.363		

TABLE VII

Average Nitrogen Contents of Sewage

Free ammonia	32.00 p.p.m.
Organic nitrogen:	
Total	27.00 p.p.m.
Dissolved	18.00 p.p.m.
Nitrites	0.26 p.p.m.
Nitrates	0.00 p.p.m.

Nitrites and nitrates are frequently absent, and the sewage was frequently septic during the summer months, but very seldom during the other seasons.

TABLE VIII

Daily cycle of sewage, showing hourly changes in strength

	Suspended Solids			Oxygen Consumed*	
	Settling **c.c. per l.	Total p.p.m.	Volatile p.p.m.	Total p.p.m.	Diss. p.p.m.
Midnight	1.6	135	111	58	42
2 a. m.	1.4	168	137	58	39
4 a. m.	1.8	128	107	51	36
6 a. m.	1.0	93	74	39	27
8 a. m.	1.4	88	64	36	25
10 a. m.	2.0	146	110	67	46
Noon	2.0	196	159	81	48
2 p. m.	1.7	177	139	72	47
4 p. m.	2.3	190	147	84	51
6 p. m.	2.1	187	147	96	59
8 p. m.	2.2	183	140	88	56
10 p. m.	1.5	149	115	70	48
Midnight	1.6	135	111	58	42

* Oxygen consumed in thirty minutes at 100°C. Diss. is from filtered sample.
** The settling suspended solids in the first column are obtained by means of the Imhoff cone.

One of the notable features of the local sewage is the large proportion of colloidal suspensa in very finely divided condition, which settles very slowly if at all. The different tanks removed a satisfactory percentage of settleable solids, but to a large extent this non-settleable material remained in the sewage.

That portion of this fine material which disappeared in passage thru the tanks probably did not settle but was dissolved.

Experiments in Imhoff settling cones were made to determine the average rate of sedimentation. The volume of material in the apex of the cone was read after the expiration of varying intervals. The following results, obtained from an extensive series of observations, are averages of the quantity of settling matter in cubic centimeters per liter, and, assuming the average amount settled in two hours equal to 100 per cent., the percentages, for shorter periods are given.

Time Minutes	Settlings c.c. per liter	Per Cent. Settled
5	0.629	33.1
10	1.109	58.3
15	1.188	62.5
30	1.359	71.5
45	1.480	78.0
60	1.490	78.4
120	1.900	100.

The above matters, settling per liter, were equivalent only to about 69 p. p. m. of the sewage, which contained 162 p. p. m. of suspended solids. In other words, 1.90 c.c. per liter represents only about 43 per cent. of the suspended solids. The remainder would not settle in a two-hour period, and even in six hours but a small portion of it would settle. It is obvious, therefore, that the tanks would not remove in two hours a greater proportion than could be removed in the cones. In the results of removal effected by the tanks given in the tables which follow, this should be understood. The tabulated figures refer to the constituents observed in the sewage and in the effluents. In Table XIV the percent of removal is also shown.

The removal of 43 per cent. of total suspended solids might be stated as far as the tank is concerned, as equal to a removal of 100 per cent., because it is quite clear that the tanks cannot remove in two hours any more solids by sedimentation than a cone can in the same interval of time.

That the Imhoff cone should be a more efficient remover of suspended solids than the tanks is not in the least surprising, when it is recalled that in the cone, sedimentation is quiescent and theoretic retention is 100 per cent. efficient—while in the tank there is always some movement in the settling sewage and the depth is several times greater than in the cone, and it follows that particles reach the bottom of the cone considerably quicker than they do the bottom of the tank.

In the studies made on the Brooklyn sewage, experiments were undertaken by Mr. W. T. Carpenter to ascertain some of the phenomena attending the sedimentation of sewage solids. These studies were too elaborate to be given space in this paper, but as one set of experiments illustrates the effect of depth on sedimentation, and fineness, or colloidal condition of suspensa, sufficient of it will be given to bring out this point.

The apparatus used consisted of 2-inch diameter galvanized iron pipe terminating in a coupling into which was cemented the lower part of an Imhoff cone, thus giving a chamber in which settling matter was visible and could be measured volumetrically. The apparatus afforded a sedimentation depth of 74 inches. The capacity was that of a measured sample bottle, which was filled with the sewage or tank effluent to be tested. The contents of the bottle were discharged into the apparatus as quickly as possible. The volume of sediment forming at the apex was read at intervals of 15 minutes, 30 minutes, and at 1, 2, 3, 4, 5, and 6 hours.

A large number of such tests were made on crude sewage, and also on Imhoff tank effluent, using that from tank 3.

The figures given are averages of all the tests. For comparison, figures showing rate of deposit in the ordinary Imhoff cone on the same sewage and effluents are also given.

TABLE IX

Volume of Deposit and Time of Settling

Observed in Imhoff and Special Cones
Quantities in c.c. per liter

Time	Imhoff Cone Sewage	Imhoff Cone Effluent	Special 74-in. Cone Sewage	Special 74-in. Cone Effluent
Minutes				
5	0.63	0.0	......	......
10	1.11	.12	......	......
15	1.19	.20	0.52	0.07
30	1.36	.29	.90	.10
45	1.48	.36	......	.13
Hours				
1	1.49	.40	1.33	.15
2	1.90	.47	1.69	.20
3	2.30	.50	1.89	.25
4	......	......	1.97	.28
5	......	......	2.02	.32
6	......	......	2.03	.33

Sewage and effluent tested*

Contents of	Sewage	Effluent	% Removed
Total solids	162 p.p.m.	97 p.p.m.	40
Settling solids	92 p.p.m.	23 p.p.m.	66
Colloidal solids	93 p.p.m.	74 p.p.m.	20

* Effluent is from Imhoff Tank 3.
% of removal given was effected in the Imhoff tank.

Experimental Data From the Imhoff Tanks and Settling Tanks (Dortmund Type) With Short Retention Periods.

The station was provided with three Imhoff tanks, so designed that they differed in depth and cubic capacity only. Each tank was a wooden cylinder, 15 ft. in diameter. They were placed along the northerly side of the plant, extending east from the quieting tank, from which each received sewage thru an independent flume, the sewage entering the flume thru an adjustable measuring orifice. The plant was also provided with four plain settling tanks (Dortmund type), which received sewage from the quieting tank in the same manner.

The principal dimensions of these tanks are shown by means of Table X, and the accompanying sketches.

For the purposes of this paper the three Imhoff tanks and settling tank 3, will be considered in one group, as, during the period of the tests described on the Imhoff tanks, settling tank 3 was operated on the same sewage in connection with a separate digestion tank, which daily received the solids settled out. The two tanks acted the part of an Imhoff tank with the two stories separated.

The direction of flow thru the Imhoff tanks was from north to south. The tanks were so connected with the other units of the experimental plant, that Imhoff effluent could be obtained by gravity flow for all. The three tanks were similar in design. Inlet and outlet weirs were full width of the flowing-thru chamber, and were of the same design in each case, as were also the hopper

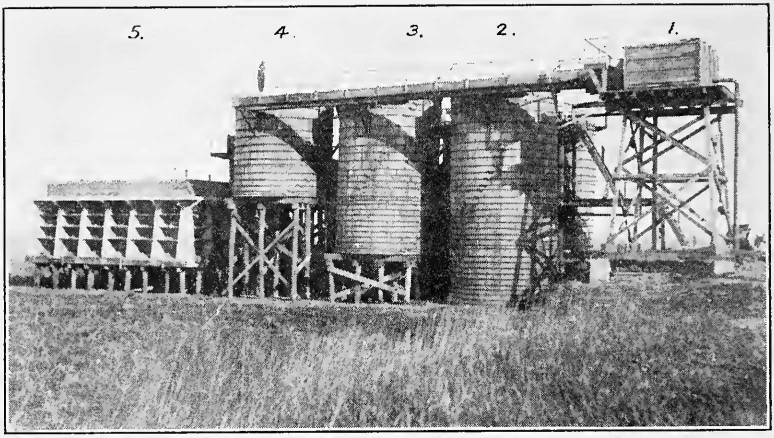


Fig. 7. View of Experimental Tanks from the North.

1. Quieting Tank.
2. Imhoff Tank No. 1.
3. Imhoff Tank No. 2.
4. Imhoff Tank No. 3.
5. Sprinkling Filter Beds.

Capacity of Plant—1,200,000 gallons per day of sewage was used in the various experimental processes.

Man is seen taking samples on top deck of Imhoff Tank No. 3, just under Fig. 4.

The Imhoff Tanks are 15 feet in diameter inside.

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bottoms, the 8-inch-diameter sludge outlet, the settling-chamber floors, slopes and slots. The tanks differed only in the matter of depth. The water line in each was at elevation 31.17.

The slots for the passage of settled matters from the slopes into the digesting chamber were so designed that the plane of each slope was carried without obstruction directly thru into the digesting chamber, *on each side*. The slopes did not pass the one under the other, as is often observed in American practice. The latter design was avoided, as with it the settlings on one slope must turn over upon the other slope in order to pass thru into the digesting chamber, thus making obstruction probable and calling for frequent cleaning of slopes and slots. See Fig. 9, at 1 and 3. The design adopted to avoid this (Fig. 9, at 2) was to guard the slots, or openings from below, from rising gases by means of an A-shaped shield or baffle which afforded a slot on each side. The upper surfaces of the A-shaped shield were exactly in the *same plane* as the slopes of the flowing-thru chamber, so that when sediment started to slide, it found an opening directly in its path thru which it could pass without stopping or turning in its course. This is believed to be an important prac-

tical point in the design of these tanks. It was so successful that slopes, inclined only about 42 degrees from level, did not at any time become clogged in five years' service, and never needed to be squeegeed down. The width of each slot on the plane of the slope was 6 inches. The inclination of slope above mentioned was put in as the least slope that might be expected to work with success. Arrangements had been made to increase it if necessary, but no such change was made.

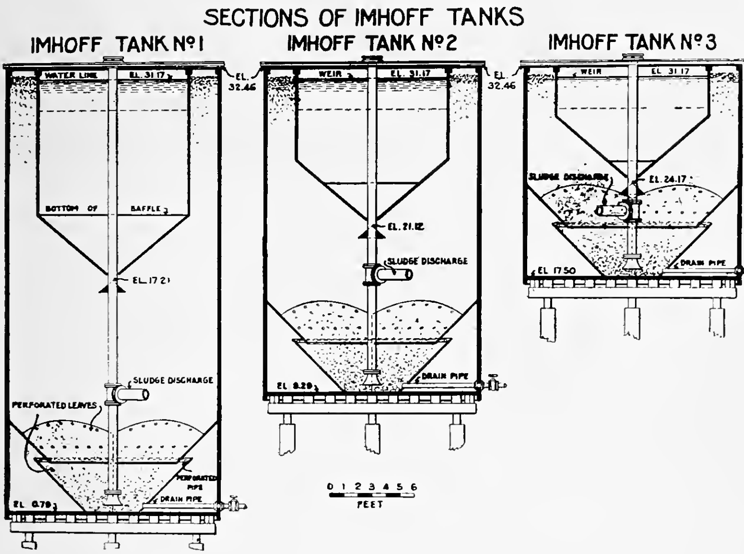

Fig. 8.

The bottom of each digesting chamber was formed inside of the cylindrical tank in the shape of an inverted truncated hexagonal pyramid, made in two sections, the upper overlapping the lower. A perforated lead pipe 1¼ inches in diameter was placed entirely around the overhanging edge of the upper section of pyramid, and connected with the city water supply, for use in starting sludge, etc. The water was controlled by a gate valve. The use of this pipe never was called for in the operation of the tanks.

Scum boards 18½ inches deep were placed at inlet and outlet weirs, one foot from each weir, and were used thruout the experiments.

Baffles were not provided at first, but the necessity for them was demonstrated as the experiments progressed, and they were then put in, after considerable study as to their position, shape and depth.

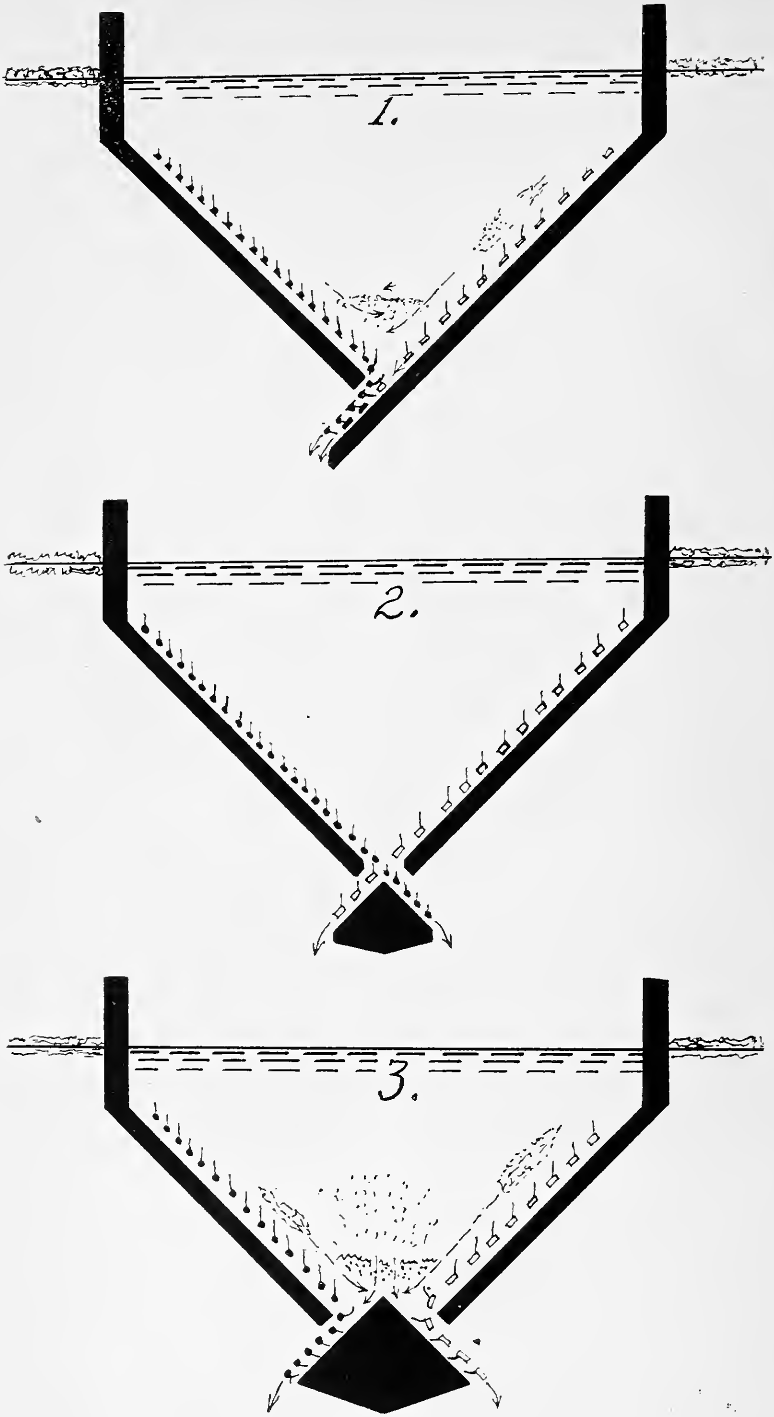

Fig. 9.

1. Type of Slot Frequently Used in American Practice.
2. Type of Slot Used on all the Brooklyn Imhoff Tanks.
3. Type Sometimes Used.

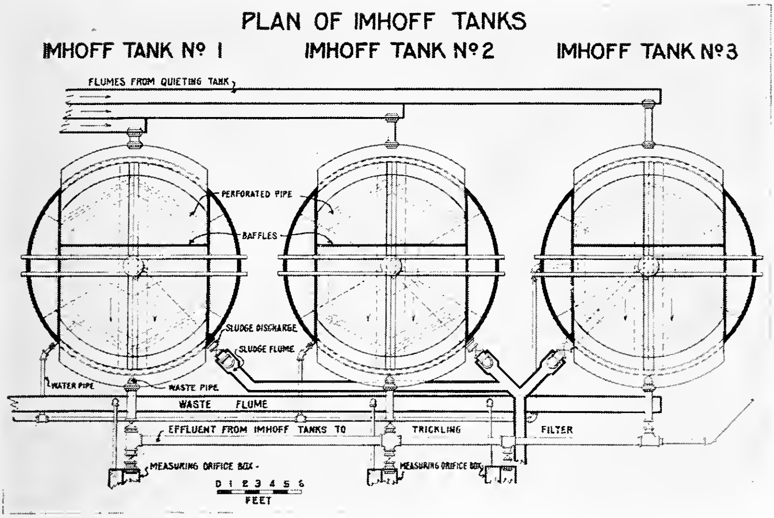

Fig. 10.

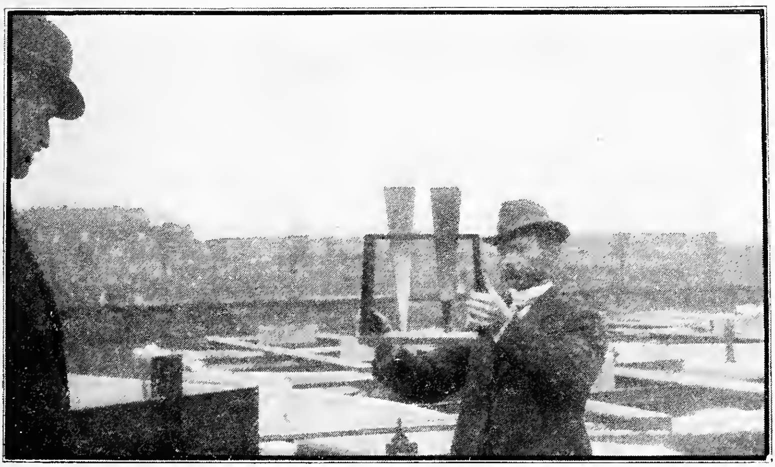

Fig. 11.

The gas vents, being segments of the 15 ft. diameter circle, cut off by the walls of the flowing-thru chambers, were 2 ft. wide at their greatest width. They were at all times ample for the purpose.

The tanks were completed and put in service October 1, 1913, and a few days later, at the suggestion of Dr. Rudolph Hering, ripe sludge was obtained from the tanks of the Pennypack Creek

sewage disposal plant near Philadelphia, and with this each tank was seeded. The ripening period extended thru the severe winter of 1913-1914 and was not completed in either of the tanks until May 21, 1914, when No. 2 and No. 3 gave ripe sludge, but No. 1 did not ripen until June 11. The tanks, however, all continued to improve in operation during the year 1914. Early in the spring there was considerable smell from all of them, but this disappeared during the summer, and did not return until the following spring. Improvement continued thruout the entire period of operation, and the tanks were doing their best when finally shut down in 1918. At no time during the experiments was there any evidence of sludge accumulating on the slopes of the settling chambers. As stated elsewhere, the slopes inclined only 41 degrees 43 minutes from level. It had been intended to try a number of different angles of slope, beginning with the least which it was convenient to place, with the expectation that cleaning would be necessary with slopes inclined from level less than 50 degrees, but there seemed no reason to increase the inclination after installing the slopes. The surfaces of the slopes were of planed boards, with the grain running with the slope. It is quite possible that this surface is less subject to affording points of adhesion for settling matters than concrete would be, but as it was considered perfectly feasible to use an inclined floor of planed boards for the slopes in a full size plant, it was decided not to go further in this study, but to adopt an angle of inclination in future tanks as much greater than 42 degrees as the other conditions would permit. The double slot placed at the lowest point, i. e. the intersection of the planes of each side, without permitting the crest of the baffle to emerge into the settling tank and form an obstruction to sliding matters,—was of much importance in keeping the slopes clean. The settlings do not appear to go thru the slot at the foot of the slope down which they slide, unless they are heavy. The light-weight materials and much of the heavy, appear to jump over this space and go thru the other slot, which does not require a change in their direction of movement (see Fig. 9). It appears from the work of the Brooklyn tanks that the design of slots is far more important in its relation to tank operation than has been generally recognized in practice.

The phenomena which accompany foaming and frothing in the Imhoff tanks are so various that it must be admitted that many explanations are possible. Tanks will foam when no sludge is present, and also when filled with sludge—and when much or little is present. The suspended matters are so light in specific gravity that any cause which gives rise to a rapid gas formation may result in foaming, even changes of barometric pressure in the atmosphere may cause it. The presence of grease in the tank and an acid reaction, seems to be one of the most persistent conditions noted when foaming takes places. But

foaming takes place when the condition is not acid and there is but little grease present, and when explanation seems impossible. At times during the experiments, and without any apparent reason, the entire body of sludge in the digestion chambers of the different tanks would rise to the top, usually without foaming or frothing, and remain for a day or two, then slowly settle. On such occasions, if foaming did not occur gas discharge from the gas vents was at least more than usually active and large eructations of foul gas were noted. At such times there was considerable odor present, and when foaming occurred there was a strong and very persistent odor. Churning the scum with a hoe in the gas vents, or breaking it up with a paddle, usually sufficed to release the entrained gas and permit it to settle. A jet from a hose is probably the most effective method of doing this. At no time was the foaming so serious that it could not be controlled, but while it lasted the tank gave forth bad smells, and its efficiency as a remover of suspended matter decreased more than half. The settling chambers were at no time involved in foaming and very seldom showed any scum.

The regrettable thing about this bad habit of the Imhoff tank is that even if it can be controlled it causes bad odors, which makes it a very uncertain risk, and a bad neighbor, and suggests that such tanks should not be placed near enough to habitations to give rise to damage claims or cause complaint. If it is necessary to put such a tank near inhabited structures, where complaint is at all probable, it should be covered with a building that would keep in the odors, when these occur. It is a simple matter to provide a building which will insure a neighborhood against nuisance from odors and at the same time permit the use of this tank, which is otherwise such an excellent apparatus for sewage treatment.

The settling tanks (Dortmund type) never showed the least inclination to foam, and never gave forth odors that could be recognized as coming from sewage a few feet away. This may have been because they were not intended for, or used as digesting or septic tanks, the settling matters and sludge being removed daily for other treatment.

It may be added that the Imhoff tanks very seldom caused odors, and at times when they did, if it was not due to foaming, it was probably due to a septic condition of the sewage entering them. At one time during the experiments all of the tanks caused odors, and it was discovered that the main sewer had become very foul from deposits. After the sewer was cleaned out these odors ceased, and did not occur until the sewer again required cleaning. When this was done, odors again ceased, at least suggesting the connection between bad smells from a disposal plant, and neglect in keeping sewers clean.

The idea that sewers and disposal plants will run without

causing trouble if left to take care of themselves, is erroneous as we all know, but it is not sufficiently understood that troubles with the disposal plant are frequently caused by neglect in cleaning out the sewers.

For some reason not understood by the writer, the Imhoff tank, while being installed more and more extensively by engineers, has fallen into disrepute in public opinion. In rather extensive travels around this country during the last few years, the writer has visited many such tanks, and plans of new installations are constantly appearing in the technical papers, yet, on visiting various plants in operation, many complaints were heard, and the general consensus of opinion was decidedly unfavorable. What is the reason for this attitude on the part of those who are maintaining and operating these tanks? There is nothing worse than to give a dog a bad name, and many a good dog has been condemned for this reason.

The Imhoff tank has been closely studied by the writer, and while his judgment may be prejudiced in its favor, and he may be told that his explanations of its failures are nothing more than apologies, yet he feels that they are entitled to a hearing at least. His first studies of the tank were received from Dr. Imhoff, himself, nearly ten years ago, and he had the opportunity of visiting with Dr. Imhoff all of the larger and some of the smaller installations in the Emscher district in 1912, and hearing at first hand the principles upon which the designs were based, and of the various investigations which had been made on various points concerned both in the design and in the operation of these tanks. In 1913 Dr. Imhoff spent some of his valuable time in the writer's office in Brooklyn, discussing the design of the three tanks described in this paper, he having permitted their use without charge for experimental purposes. Many of the features of the tanks were made to conform especially with his views and instructions, so that the design in reality was his and not the writer's—and to him alone is due the credit for their success. The writer has, since 1912, visited many American installations of the Imhoff tank, and while he must admit some troubles in operation, and smelling some odors not very bad to a sewage expert, but killing to neighboring residents who had the possibility of damages in prospect, he feels that the public has been unjust in its generally unfavorable attitude. There were, however, not a few instances of troubles, for some of which the designers, and not Dr. Imhoff, were to blame, and others which were due to mismanagement, and still others to gross overloading, and even to entire neglect. The tank is admitted to be delicate to operate, and requires constant care and good management, but this is true of disposal plants generally.

It was assumed by the designers of the early American Imhoff tanks, that since American sewage is weaker than German, the

digestion chamber of the tank might be made smaller. But the truth probably in most cases is that American sewage as a rule forms a sludge with a larger per cent. of water than is the case abroad, and that its volume is actually greater in consequence, and requires more space for digestion.

Whatever the various causes of foaming may be, it appears certain that sludge arising above the slot-line will cause it, as well as turn the entire tank above and below into an ordinary septic tank. And whenever this condition does occur an active nuisance from smells is inevitable. In spite of all that can be said against the tank, it must be allowed that its advantages are such that a certain amount of the risk of nuisance may be justified. But one should not hide the truth that such a risk exists, and every tank which is not carefully operated will probably cause local trouble.

The design of these tanks calls for the highest knowledge of sewage treatment, and of the peculiar qualities of sewage solids, grease, etc., and should never be undertaken without the most careful study. Not a few engineers who have ventured into this field look back with sorrow on their first tanks; and this has had much to do with public feeling regarding the Imhoff tank.

TABLE X

Tank Data, Imhoff Tanks

	Imhoff Tanks 1	2	3
Elev. water line, ft.	31.17	31.17	31.17
Elev. bottom of tank, ft.	0.79	9.29	17.50
Elev. slope intersection, ft.	17.21	21.12	24.17
Diameter of tank, ft.	15.00	15.00	15.00
Depth, total, ft.	30.38	21.88	13.67
Width of settling chamber, ft.	10.67	10.67	10.67
Depth of settling chamber to slots, ft.	13.97	10.05	7.00
Depth of settling chamber to slopes, ft.	9.22	5.30	2.42
Slopes inclined from level, degs.	41° 43′	41° 43′	41° 43′
Depth of scum boards, ft.	1.54	1.54	1.54
Depth of baffles, ft.	9.50	7.79	5.54
Capacity below w. l., cu. ft.	1,610.00	1,113.00	557.00
Capacity below w. l., gals.	12,050.00	8,325.00	4,166.00
Capacity 1 hr. retention, gals.	290,000.00	200,000.00	100,000.00
Capacity 2 hr. retention, gals.	145,000.00	100,000.00	50,000.00
Digesting chamber diameter, ft.	15.00	15.00	15.00
Digesting chamber depth, ft.	16.42	11.83	6.67
Capacity below slot-line, cu. ft.	2,128.00	1,317.00	469.00

TABLE XI

Tank Data, Settling, Digestion and Humus Tanks

	Settling Tanks 1-4	Digestion Tank	Humus Tanks
Elev. water line, ft.	7.80	+6.50	6.02
Elev. top of hopper bottom, ft.	3.80	—4.50	....
Elev. bottom hopper bottom, ft.	0.20	—7.00	—3.90
Depth below w. l., ft.	7.60	13.50	9.92
Size water surface, ft.	8x8	D.5.00	5.6x5.6
Capacity, cu. ft.	285.00	265.00	127.00
Capacity, gals.	2,132.00	1,988.00	950.00
Capacity 1 hr. retention, gals.	51,168.00	....	22,800.00
Capacity 2 hr. retention, gals.	25,584.00	....	11,400.00

Theoretic and Observed Retention

The term "theoretic retention" in this study means the time required to fill a tank at the rate of flow under consideration. It is well known that the true retention is always less than the theoretic, and to what extent the tanks at the station differed from the theoretic was of much interest in the interpretation of phenomena. Observation led to the conclusion in advance of study, that the difference between the theoretic and the actual must be considerable.

Different means of determining this point were tried, and in fact none proved entirely satisfactory. That which was considered the best was determination by means of dyes. Ammonium chloride and sodium chloride were previously tried, but were rejected because of the high specific gravity of their solutions, which caused them to fall to the bottom and pass out very slowly, giving too long a period.

Fuchsin dye, by reason of its great strength and the ease of comparing its solutions with standards, gave fair results. The dye was applied at the entrance end of the tank, and samples were taken from the effluent at short intervals until it had disappeared. The intensities of color expressed in per cent. of maximum were plotted as ordinates with time intervals from the application as abscissae, and a curve adjusted to them. The area of this curve should represent the total quantity of dye used.

The portion of the area to the left of any ordinate line should represent the dye which has passed out, and that to the right, the dye still retained in the tank.

The abscissa of that ordinate that bisects the area should, therefore, be the time of retention. This represents the time of the passage of the sewage, and should be the actual retention period. There are, however, a number of difficulties with the method. To recognize the actual first appearance of color in the effluent is not easy, nor is it easy to recognize the last trace, and the extent to which fine colloidal matter in the sewage and settling solids may carry down the color is also an unknown factor. The results of the tests, however, are of much interest and give valuable comparative information. The accuracy of the tests and the conclusions founded on them are questionable, and the results should not be taken as demonstrations of the actual, or anything near the actually true retention, under average conditions of operation.

A difficulty that appears to be fundamental is, that such observations hold good only for the retention period from which they are obtained. Thus a tank may show the true retention to be 80 per cent. of the theoretic for a 3-hour retention period, while it may also be found only 40 per cent. of the theoretic for a 2-hour retention period. In other words, the tank is not

standardized by this method for all periods, and cannot be, for its efficiency is different with every rate of retention. Each tank, however, has its best retention period.

As the 2-hour period appeared to be the best suited for tank operation at this location, most of the experimental work was done with this period.

The following statement shows the result of the Fuchsin dye test on the different tanks:

TABLE XII

Imhoff Tank	Theoretic Retention	Sewage Per Day	Observed Retention	Loss of Retention	Suspensa Removed
No.	hours	gals.	hours	%	%
1	2	145,000	1.00	50	61
2	2	100,000	1.00	50	56
3	1	100,000	0.33	68	51
Settling Tank No.					
3	2	50,000	1.77	10	77

As observed by use of Fuchsin dye.
Observations in June-July, 1915.
Tanks all working poorly except settling tank 3.
Suspensa removed determined by Imhoff cone.

Effect of Baffling on Imhoff Tanks

As originally constructed the tanks were not provided with baffles, as it was intended to determine by observation whether these were necessary, and if so, the proper depth and location for them.

When all the tanks were operated on a 2-hour theoretic retention, during a 3-months period, their comparative efficiency in the removal of settling matter and suspended solids was noted, revealing marked differences between them. The data led to the conclusion that the flow in all three tanks reached down only to a limited depth, regardless of the depth of the settling chamber. The dimensions of these chambers are shown in Table X. The length and breadth of flow is equal in each settling chamber, but the depth and cubic capacity of each is different from the others. To agree with theoretic retention, with the same quantity of sewage flow passed into each tank, the retention period should agree directly with the cubic capacity. To test this theory the three tanks were each put in operation at the rate of 75,000 gallons per day, giving the following theoretic retention to each, with the result shown:

Imhoff Tank No.	Theoretic Retention	Sewage Per Day	Suspensa Removal
	hours	gals.	%
1	3.8	75,000	29
2	2.7	75,000	30
3	1.3	75,000	15

Rate continued April 1 to June 30, 1914.

The average results revealed nearly equal removals in tanks 1 and 2, and an apparent loss in tank 3.

After considerable study on small models and a good deal of discussion on the hydraulics of the tanks, baffles were placed 6 ft. from the entrance weir of the chambers, which, being 15 ft. long, left 9 ft. from the baffle to the outlet weir. This was found to be the best location, at least for these tanks, and the baffles remained in this position until 1917, when some further experiments were made with the baffles in various situations. For depth of baffles see Table X.

With the baffles thus located the following data show the results obtained.

Imhoff Tank No.	Theoretic Retention	Sewage Per Day	Suspensa Removed
	hours	gals.	%
1	2	145,000	34
2	2	100,000	35
3	2	50,000	44

July and August, 1914.

The demonstration was quite convincing that at least for these tanks baffles were required. And it will be noted that the improvement was greatest in the shallowest of the three tanks, which was rather an unexpected result.

Floating Scum on Imhoff Tanks

Floating scum was but seldom present in the settling chambers, and when present usually consisted mainly of grease which separated out from the sewage matters. The scum boards were quite efficient in preventing floating matters. Such scum and other materials as collected behind the scum boards were paddled from time to time, and settled without causing much trouble. When necessary, materials that did not settle were thrown into the gas vents.

Floating scum in the gas vents, taking the period from January, 1915, to the end of April as representative, was made up as follows:

TABLE XIII

Quantities Given in Per Cent. of Total Constituents

	Imhoff Tank 1	2	3
	%	%	%
Moisture	80.2	81.5	84.6
Solids	19.8	18.5	15.4
Mineral	26.0	27.7	30.5
Organic	74.0	72.3	69.5
Fats	26.6	25.4	11.2
Average depth of scum, inches	3.75	1.50	0½

Effect of Imhoff Tanks on Bacterial Content of Sewage

The effect of passing sewage thru tanks on the bacterial content of the sewage is a doubtful matter, as the results are so various and differ so much with the different methods employed. The determination of this for the Brooklyn sewage was rather

more interesting than important. It was assumed that should disinfection prove necessary a trickling filter plant would be installed, and the question of bacterial removal would arise only in connection with an oxidized effluent. Moreover, the writer believes that much discrimination is called for in selecting and interpreting the results of a purely biological study, and the scope of the experimental work did not require that this be included as of primary importance, but a means of interpreting other work and checking results. In the warmer months of the year with septic sewage and much daily departure from average biological conditions, the results would be masked by these conditions and of no great value, and might mislead. In the cold months no valuable results bearing on the local problem were to be expected. It therefore appeared that the results obtained in the spring, especially March and April, were about the best for this study, and the city was fortunate in having some tests made by experts in this line of work at the very time when the results would be of the most interest, and not marked by the many misleading factors existing in summer and winter.

The tests referred to were made by Messrs. Lederle & Provost, at the Lederle laboratories in New York, and at the experiment station laboratory, in March and April, 1915, in connection with a study, made with the city's consent, for a client who had retained these experts to experiment with and report on ozone disinfection of sewage and effluents.

The sewage tested was taken from the ordinary crude sewage, and the Imhoff tank effluent represents tank 2 only. The retention period was 2 hours.

TABLE XIV

Average Bacterial Counts, and Chemical Constituents With Percentages of Reduction

March 24 to April 13, 1915, Inclusive—Parts Per Million

	Crude Sewage	Effluent from Imhoff Tk. 2	% Reduction
Dissolved oxygen consumed	148.	89	39.9
Total suspended matter	256.	179.	30.1
Mineral, in suspensa	72.	42.	41.7
Organic, in suspensa	184.	137	25.5
Total solids in sewage	739.	618	16.4
Total minerals in sewage	361.	326	9.4
Total organics in sewage	378.	292	22.8
Nitrates	0.38	0.25	34.2
Oxygen consumed	91	72	20.8
Tank retention (theoretic), 2 hours.			

Bacterial Counts Per C. C.

	Crude Sewage	Imhoff Effluent	% Changed
Agar, 24 hrs. at 37°C	250,000	214,000	—14.4
Gelatin, 48 hrs. at 20°C	600,000	988,000	-|-64.7
Bacteria of B. Coli type	42,000	107,000	-|-154.3

— Indicates reduction.
-|- Indicates increase.

It should be noted that the sewage during the period of these biological tests was considerably stronger than the averages for the two months, parts of which fell into the test period. This was probably caused by the movement down the mains of the sewage system of the deposits that had been formed during the winter, brought about by melting snows and rains. On account of conditions caused by a heavy rain fall, the sewage and tank effluent results for March 26 were excluded from the above table. As these results are of interest as showing what storm conditions can do at this plant, they are given below:

TABLE XV

Bacterial Count and Chemical Constituents of Sewage

March 26, 1915—Parts Per Million

	Crude Sewage	Effluent from Imhoff Tk. 2	% Reduction
Dissolved oxygen consumed	143.5	105.	27.
Total suspended matter	236.	172.	27.
Minerals in suspensa	74.	26.	70.
Organics in suspensa	162.	146.	10.
Total solids in sewage	822.	606.	26.
Total minerals in sewage	380.	352.	7.
Total organics in sewage	442.	254.	42.
Nitrates	0.42	0.14	41.
Oxygen consumed	77.5	67	13.
Tank retention (theoretic), 2 hours.			

Bacterial Counts Per C. C.

	Crude Sewage	Imhoff Effluent	% Changed
Agar, 24 hrs. at 37 C.	20,000,000	4,752,000	—76.
Bacteria of B. Coli type	1,000,000	258,000	—74.
— Indicates reduction.			

It is obvious from the above that the storm-sewage problem in Brooklyn is both important and very difficult of solution. The Imhoff tank showed a very gratifying removal both of bacteria and suspensa under the conditions, but the size of tanks required to treat the storm flow would make the tax payers sit up and take notice. A plain sedimentation tank would probably have done the same work.

Settling Tank 3, and Separate Digestion

Settling tank 3 (Dortmund type) was 8 ft. x 8 ft. in plan, with a vertical depth of 4 ft., and a hopper bottom, having its apex line 3.6 ft. making the greatest total depth 7.6 ft. Its water line was elevation 7.80.

The flow, entering thru a pipe, was carried down near the center, and discharged into the tank 5 ft. below the water line. The effluent was taken off thru V-shaped notches in the sides of the outfall trough, that surrounds the top on all four sides. Eight notches were provided, two on each side. A 6-in. sludge-dis-

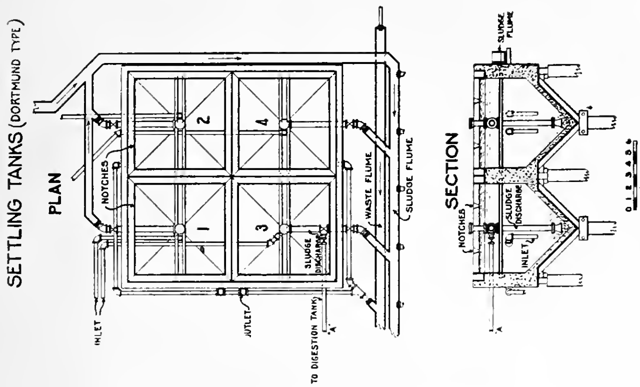

Fig. 12.

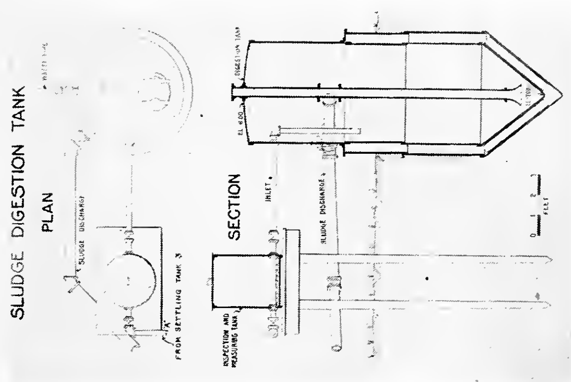

Fig. 13.

charge pipe was placed in the center, ending with a bell at the bottom, and having a clean-out at the top above the water line. Sludge was discharged from this pipe thru a horizontal branch placed about 2 ft. below the water line and, passing thru the south wall of the tank, discharged thru a gate-valve into the flume leading to the sludge-drying beds, etc.

Before passing thru the wall, this horizontal portion of the sludge pipe gave off a branch, consisting of 4-inch pipe controlled by a gate-valve, which passed to a sludge-measuring tank, into which the daily settlings and sludge deposited in the hopper could be discharged and measured, and from which they could be fed slowly by gravity into the sludge digestion tank. (See Fig. 13).

The "digestion tank", or digesting tank, was of steel plate, made to be air and water-tight, 5 ft. in diameter and 15 ft. deep, with a conical bottom. It was set vertically in the ground, the

top of the tank being at elevation + 8.00. The lower portion was provided with an outside shell, with an air space between it and the tank.

A sludge-discharge pipe, and an overflow pipe for water, also were provided; a "clean out" for the sludge pipe, and a manhole in the top that could be sealed airtight. To test the gases produced in digestion, a small valve was put in the top.

Operation began with filling the tank with tap water to elevation + 6.50, the overflow level. Sludge having been passed from the settling tank hopper to the measuring tank, where test samples were taken, and the quantity measured, was then permitted to enter the digestion tank, the gate valve on the overflow pipe being opened, allowing the water displaced by the entering sludge to escape.

The operation of this tank was entirely successful; never at any time were the gases given off offensive; the surplus water escaping thru the overflow when the tank received its charge of sludge never carried offensive odors. The gases given off thru the valve at the top were odorless, and burned with a colorless flame when ignited, consisting mostly of methane gas.

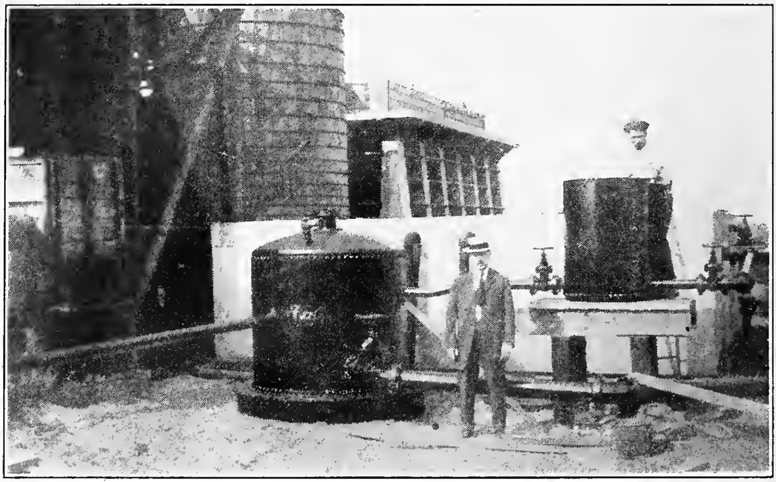

Fig. 14. Sludge Digestion Tank.

This is a method of doing the work of the Imhoff Tank in two separate tanks and is remarkably promising. The sewage settles in a plain sedimentation tank and the settlings are drawn daily under the hydraulic head of the settling tank and discharged into the digestion tank; supernatant water being let out of the overflow to provide room and draw in the sludge and settlings. The digested sludge is dried on Imhoff drying beds, and is of the same quality as Imhoff Tank sludge.

Sludge ripened in this tank perfectly, and could not have been distinguished from Imhoff-tank ripe sludge. It was full of gas bubbles and dried readily on sludge beds.

The operating depth of the tank was 13.5 ft. The net cubic capacity for digesting sludge was 265 cu. ft.

Settling tank 3 had a net capacity 285 cu. ft., and working at a theoretical 2-hours retention treated 25,584 gallons of sewage per day, equal to the sewage of 250 people, the digestion tank thus affording only a space of 1.06 cu. ft. per capita, which with this arrangement of tank appeared to be sufficient for producing a good, ripe sludge. This is much less space than proved necessary in the Imhoff tanks themselves, and did not allow much extra room for sludge storage. As soon as ripe sludge appeared in the hopper it was discharged and dried. It is very doubtful if a large tank of this kind would be successful with less sludge capacity per capita than the Imhoff tanks require. In operating a large tank, sludge drying would be much more troublesome on account of the quantity of sludge. A small amount of ripe sludge takes little room to dry, a large amount takes a great deal of room, and drying can only be done in favorable weather.

It is possible that in the combination of a settling tank with a separate digestion tank, less space is required for digestion than is the case in the digesting chamber of a two story tank because of the fact that raw sludge is discharged into the digestion tank at intervals of 12 to 24 hours, instead of continually; the settling tank in this case doing part of the work of the digesting chamber; this at least seems to be a fair inference from the writer's experience.

Ripening of sludge in the separate digestion tank was much more rapid than in the Imhoff tanks. On being started the tank was seeded with a few gallons of ripe Imhoff sludge, which may have helped. Operation began late in March, and on July 27, four months after starting, 26 cu. ft. of ripe sludge was withdrawn. On September 17 all the ripe sludge was withdrawn, and no further sludge added for digesting, for several months. During this period it produced in ripe sludge up to the time of the shut-off, 78 cu ft., and later the unripe sludge remaining after the shut-down digested completely, giving 20 cu. ft. more, in all 98 cu. ft. The ripe sludge contained before drying 94 per cent moisture and dried to 64 per cent. moisture; it averaged about 37 per cent. volatile, as compared with the Imhoff sludge which average more than 45 per cent. volatile.

Effect of Depth of Tank and Capacity of Digestion Chamber on Quality of Imhoff Sludge

Accurate information on the best depth and the capacity of digestion chamber, altho of extreme importance in the design of

a permanent sewage-treatment plant, is unfortunately very difficult to obtain, but we believe that the results secured in our work cover our design requirements.

There appeared to be three ways of securing the above desired information. First, by sounding for the sludge level; second, by securing samples at different depths, and third, by observations on the behavior of the tanks, when run without sludge withdrawal, thruout a period believed to represent our sludge-storage requirements, considered in connection with average data on the character of the sludge subsequently withdrawn.

Determination of the sludge level by means of soundings was at all times subject to uncertainty. The same may be said of the method of obtaining samples at different depths. Sounding and sampling could only be performed thru the gas vents, the shape of which, together with that of the tank bottom, interfered greatly with these methods. Even if the design had not interfered with these methods, the phenomena observed in the tanks rendered the observations nearly useless. The ebullition of gas was so active, and caused so much circulation in the contents, that the upper portion of the sludge was disturbed and kept very fluid. The more successful the tank, the more difficult was the operation of finding the sludge level. Even the ripe sludge ready for withdrawal was so fluid that a sounding appliance readily sank thru it. The most that can be said from these observations is that there is a gradual increase in the density of the sludge from the level of the slots to the bottom of the tank. This, at least, was the experience at Brooklyn.

This condition has been described by other observers. At Fitchburg, it was found that the best way to ascertain the amount of sludge present was to use a pump with a hose for a suction line, which was lowered slowly, and the contents of the tank, thus removed from different depths, gave the information sought. It is stated in the report describing the experiments at Philadelphia concerning the Imhoff tank that "one of the mechanical difficulties was the inability to determine at what level the sludge stood in the digestion chamber, and altho sludge was withdrawn in small quantities at frequent intervals, it is now believed that at times it was allowed to reach too high a level, so that the ebullition of gas forced it into the settling portion of the tank to the serious detriment of the effluent."

The third method gave more acceptable data than either of the foregoing. A long run was made for the purpose of determining the effect of depth of tank and capacity of sludge chamber on quality of sludge. Beginning on October 22, 1914, the tanks were operated at 2-hour retention without withdrawing sludge until June 22, 1915, when sludge had reached the level of the slot in tank 2, and the effluent showed marked deterioration. The tank had received sewage amounting to 100,000 gallons per

day thruout the period of observation. The inhabitants contributing sewage were estimated at 1,000. As this period covered about one month more than the assumed non-drying period, it was concluded that the storage capacity without reaching the danger point, would have been about correct for the contributing population.

As the capacity of the digestion chamber below the slots is 1,317 cubic feet, this gives 1.317 cubic feet per capita. Tank 1 received 145,000, and tank 3 received 50,000 gallons of sewage per day during the same period. At the time that the sludge in Tank 2 had reached the danger point, that in Tank 1 was apparently far below this point, thus showing the sludge storage capacity of Tank 1 was greater than necessary. Tank 3 had not reached the danger point at this time, but this tank was not considered as reliable as Tank 2 for the determination of the best capacity of digestion chamber. Tank 3 was subject to the difficulty that unripe sludge was at times discharge by "puncture." This term refers to the following phenomenon: the ripe sludge occupied so small a depth usually, that the overlying unripe sludge would at times be drawn into the sludge-pipe together with the ripe. While the proportions of the settling compartment of this tank were the most favorable for sedimentation of any of the tanks, those of the digestion compartment were the least so, and the reason appeared to be because the cross-sectional area was evidently too great for the depth. This rendered the observations for sludge-chamber capacity of less value than those on Tanks 1 and 2.

It will be seen by reference to Table XXII, that the sludge in the three Imhoff tanks had, on the average, the following solid content: Tank 1, 8.9 per cent; Tank 2, 8.9 per cent; Tank 3, 6.7 per cent. As related to the sludge-storage capacity, it will be noted that the volume occupied by any particular weight of dry solids in sludge is inversely in proportion to the percentage of solids, so that the per capita yield of dry solids in Tank 3 will occupy a volume, 8.9 divided by 6, equal to 1.3 times the volume occupied by the per capita yield in the other two tanks. Thus if 1.33 cu. ft. per capita be the allowance for a tank 20 ft. deep, 1.73 would have to be allowed for one 14 ft. deep, owing to the greater water content of the sludge.

This may be studied in a slightly different manner. If the average solid content be obtained as the result of combining individual figures weighted with the amount of sludge at the particular draft, the solid contents are as follows: Tank 1, 8.8 per cent.; Tank 2, 7.5 per cent.; Tank 3, 5.6 per cent. Calculating the volumes as above, a per capita sludge-chamber allowance of 1.33 cu. ft. in a 20-ft. tank would be equivalent to 1.12 cu. ft. in a 30-ft. tank, and to 1.86 cu. ft. in a 14-ft. tank. It should be observed, however, that the average moisture of sludge drawn from

tanks of different depths may be to a considerable degree due to the by-passing of uncompacted but fairly ripe sludge having a larger water content than the sludge at the bottom.

It would appear that the water content of ripe sludge is largely affected by the proportion of the horizontal cross section of the tank to its depth. In a shallow tank with a wide bottom, the layer of ripe sludge is comparatively thinner than the layer of similar sludge in a deep tank.

The required drying area of sludge drying beds for local conditions was found to be 0.38 square feet per capita. This is subject to assumptions as follows: That all drying shall be done between June 1 and October 1, and that time is required for removal of dried sludge and the preparation of the bed for its next sludge application; that time should be allowed for stormy periods not infrequently met during the summer. The depth of the wet sludge applied at a time is taken as not to exceed 9 inches. Observations lead us to conclude that there should not be less than ½ sq. ft. per capita. The best medium for the sludge drying beds was found to be steam ashes, a sand covering being if not undesirable, at least unnecessary.

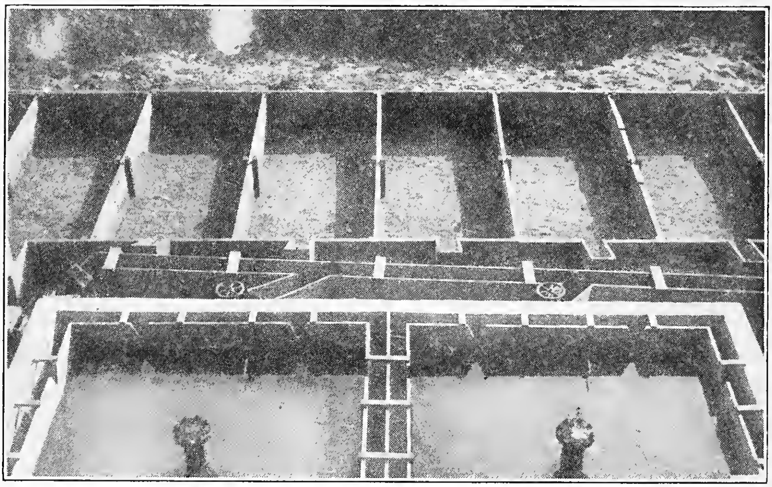

Fig. 15. Sludge Drying Beds, from top of Settling Tanks.

The digestion, storage, and drying of sludge was at no time accompanied by nuisance, even at the time when drying was delayed by storms. The dried sludge was found suitable for the filling-in of the low-lying meadow, and showed no tendency to further putrefaction. The shrinkage in volume occurring during the first day of drying amounted to about 60 per cent. The period of drying was 4 to 7 days in good weather. In stormy

weather it amounted to from 10 to 14 days. When ready for removal from the bed, the dry sludge was friable and porous, and occupied a volume not exceeding 25 per cent. of its wet volume.

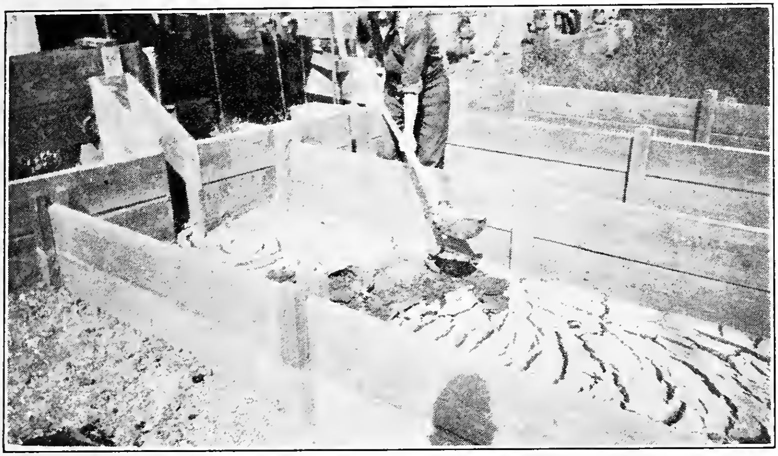

Fig. 16. Removing Dry Imhoff Sludge.

The separate digestion tank proved entirely practicable; the ripe sludge secured from it had all the best qualities of ripe Imhoff-tank sludge. It had, however, one disadvantage over the ordinary Imhoff tank, namely: the necessity of providing a man to discharge the sludge from the settling tank into the digestion tank. For satisfactory operation, this should be done at least twice daily, and in a large plant would add considerably to the expense of operation. As this is not required in the ordinary Imhoff tank, maintenance charges are more in favor of the latter.

In studying tank performance and the results of these observations on the required capacity of digestion chambers, the writer and his assistants came to the conclusion that the space per capita as determined would be too small for general use in the design of tanks for disposal plants to be operated in the ordinary manner, and that it should be made larger to avoid the danger of foaming. The larger the digestion chamber, the less danger of this appeared to exist in these tanks. Therefore, as a factor of safety it was concluded that 50 per cent. should be added to the figures obtained, when used for purposes of design, giving 2 cu. ft. per capita for a tank 20 ft. deep. The smaller the settling chamber the less danger there is of foaming. Shortness of retention, and high rate of operation are more important than high percentage of removal. The following tables give the results obtained in very short retention periods:

TABLE XVI

Sewage Supplied Experimental Plant 1914-1915

CRUDE SEWAGE	Oct.	Nov.	Dec.	Jan.	Feb.	Mch.
Temp. degs. C.	19.4	15.9	12.0	11.6	11.0	13.3
Settled in cone c.c.	1.4	1.6	2.3	2.0	2.4	2.0
SOLIDS: p.p.m.						
Total suspended p.p.m.	127	158	201	175	219	203
Settling in 2 hr. p.p.m.	....	....	....	78	97	86
Colloidal p.p.m.	....	....	....	97	122	117
Volatile p.p.m.	101	126	155	142	168	155
Volatile settling, 2 hr. p.p.m.	....	....	....	60	67	59
Volatile colloidal p.p.m.	....	....	....	82	101	96
OXYGEN: p.p.m.						
Demand p.p.m.	210	278	216	199	213	272
Dissolved p.p.m.	2.2	1.9	2.0	2.8	2.5	1.4
Saturation %	24	19	18	26	25	13
Nitrites p.p.m.	0.13	0.28	0.37	0.33	0.13	0.31
Nitrates p.p.m.	0.9	0.14	0.13	0.13	0.13	0.16
OXYGEN: p.p.m.						
Consumed, unfiltered p.p.m.	51	61	71	74	82	75
Consumed, filtered p.p.m.	35	39	44	48	52	50

	Apr.	May	June	July	Aug.	Sept.
Temp. degs. C.	15.7	18.0	20.6	22.7	22.5	23.0
Settled in cone c.c.	1.9	1.8	1.6	1.5	1.3	2.3
SOLIDS: p.p.m.						
Total suspended p.p.m.	197	192	180	147	135	205
Settling in 2 hrs. p.p.m.	74	69	50	45	43	79
Colloidal p.p.m.	123	123	130	102	92	126
Volatile p.p.m.	149	142	139	103	102	164
Volatile settling, 2 hrs. p.p.m.	48	45	36	26	27	55
Volatile colloidal p.p.m.	101	97	103	77	75	109
OXYGEN: p.p.m.						
Demand p.p.m.	270	211	276	173	216	305
Dissolved p.p.m.	0.7	1.7	1.0	0.7	0.5	0.1
Saturation %	7	18	11	8	6	1

TABLE XVII

Performance of Imhoff Tanks, 1914-1915

IMHOFF EFFLUENT TANK 1	Oct.	Nov.	Dec.	Jan.	Feb.	Mch.
Temp. degs. C.	17.5	16.4	10.1	9.8	11.1	12.1
Settled in cone c.c.	0.5	0.7	0.9	0.8	0.6	0.6
SOLIDS: p.p.m.						
Total suspended p.p.m.	94	118	146	127	142	144
Settling in 2 hr. p.p.m.	....	....	....	31	32	38
Colloidal p.p.m.	....	....	....	96	110	106
Volatile p.p.m.	76	95	117	107	102	110
Volatile settling, 2 hr. p.p.m.	....	....	....	24	16	26
Volatile colloidal p.p.m.	....	....	....	83	86	84
OXYGEN: p.p.m.						
Demand p.p.m.	113	130	101	165	187	214
Dissolved p.p.m.	0.3	0	2.1	3.1	1.4	0.6
Saturation %	3	0	19	27	13	6
Consumed: p.p.m.						
Unfiltered p.p.m.	45	58	62	60	68	68
Filtered p.p.m.	31	40	40	42	47	48
Retention hr.	2	2	2	2	2	2

	Apr.	May	June	July	Aug.	Sept.
Temp. degs. C.	15.9	18.1	21.0	23.0	23.9	24.0
Settled in cone c.c.	0.7	0.8	0.6	0.5	0.5	0.7
SOLIDS: p.p.m.						
Total suspended p.p.m.	157	154	130	112	102	122
Settling in 2 hr. p.p.m.	40	40	26	26	28	31
Colloidal p.p.m.	117	114	104	84	74	91
Volatile p.p.m.	123	118	104	82	78	95
Volatile settling, 2 hr. p.p.m.	27	25	19	17	15	17
Volatile colloidal p.p.m.	96	93	85	65	63	78
OXYGEN: p.p.m.						
Demand p.p.m.	225	197	160	135	146	244
Dissolved p.p.m.	0.3	0.4	0	0	0.1	0
Saturation %	3	4	0	0	1	0
Retention hr.	2	2	2	2	2	2

TABLE XVIII

Performance of Imhoff Tanks, 1914-1915

IMHOFF EFFLUENT TANK 2	Oct.	Nov.	Dec.	Jan.	Feb.	Mch.
Temp. degs. C.	17.5	16.1	9.8	9.0	10.9	12.1
Settled in cone c.c.	0.5	0.5	0.7	0.7	0.5	0.5
SOLIDS: p.p.m.						
Total suspended p.p.m.	91	112	132	118	134	134
Settling in 2 hrs. p.p.m.	....	....	....	30	30	33
Colloidal p.p.m.	....	....	....	88	104	101
Volatile p.p.m.	75	95	110	98	108	105
Volatile settling, 2 hrs. p.p.m.	....	....	....	24	22	21
Volatile colloidal p.p.m.	....	....	....	74	86	84
OXYGEN:						
Demand p.p.m.	66	90	80	136	156	207
Dissolved p.p.m.	0.3	0	1.5	2.7	1.0	0.3
Saturation %	3	0	13	24	10	3
Consumed: p.p.m.						
Unfiltered p.p.m.	47	57	57	58	63	64
Filtered p.p.m.	33	41	38	42	46	48
Retention hrs.	2	2	2	2	2	2

	Apr.	May	June	July	Aug.	Sept.
Temp. degs. C.	15.7	17.7	20.7	23.0	23.6	23.8
Settled in cone c.c.	0.6	0.5	0.5	1.2	0.8	0.9
SOLIDS: p.p.m.						
Total suspended p.p.m.	134	125	153	179	113	123
Settling in 2 hrs. p.p.m.	30	24	28	54	35	34
Colloidal p.p.m.	104	101	125	125	78	89
Volatile p.p.m.	106	98	123	100	106	82
Volatile settling, 2 hrs. p.p.m.	24	19	14	22	26	15
Volatile colloidal p.p.m.	87	84	105	78	80	67
OXYGEN:						
Demand p.p.m.	211	200	223	199	129	222
Dissolved p.p.m.	0.2	0.2	0	0	0.2	0
Saturation %	2	2	0	0	2	0
Retention hrs.	2	2	2	2	2	2

TABLE XIX

Performance of Imhoff Tanks, 1914-1915

IMHOFF EFFLUENT TANK 3	Oct.	Nov.	Dec.	Jan.	Feb.	Mch.
Temp. degs. C.	17.6	16.0	10.0	8.6	11.1	11.7
Settled in cone c.c.	0.4	0.4	0.5	0.5	0.3	0.4
SOLIDS: p.p.m.						
Total suspended p.p.m.	82	96	112	109	116	118
Settling in 1 hr. p.p.m.	....	....	....	26	23	20
Colloidal p.p.m.	....	....	....	83	92	98
Volatile p.p.m.	69	80	94	88	93	94
Volatile settling, 2 hr. p.p.m.	....	....	....	18	12	12
Volatile colloidal p.p.m.	....	....	....	70	81	82
OXYGEN:						
Demand p.p.m.	106	149	109	135	159	171
Dissolved p.p.m.	0	0	0.3	1.3	0	0
Saturation %	0	0	3	11	0	0
Consumed:						
Unfiltered p.p.m.	45	54	51	50	56	60
Filtered p.p.m.	33	39	34	37	41	44
Retention hr.	2	2	2	2	2	2

	Apr.	May	June	July	Aug.	Sept.
Temp. degs. C.	15.7	18.8	20.7	22.6	23.6	23.2
Settled in cone c.c.	1.4	1.1	0.9	0.6	0.7	0.4
SOLIDS: p.p.m.						
Total suspended p.p.m.	142	149	139	115	106	96
Settling in 2 hr. p.p.m.	61	41	40	28	28	23
Colloidal p.p.m.	121	108	99	87	78	73
Volatile p.p.m.	139	112	111	82	82	75
Volatile settling, 2 hr. p.p.m.	40	25	28	15	18	12
Volatile colloidal p.p.m.	99	87	83	67	64	63
OXYGEN:						
Demand p.p.m.	265	200	180	134	128	213
Dissolved p.p.m.	0.6	0.4	0	0	0.3	0
Saturation %	6	4	0	0	3	0
Retention hr.	.½	.¾	1	1	3	3

TABLE XX

Performance of Settling Tank 3, 1914-1915.

EFFLUENT FROM SETTLING TANK 3	July	Aug.	Sept.	Oct.	Nov.	Dec. to Apr. Closed
Temp. degs. C.						
Settled in cone c.c.	0.7	0.5	0.3	0.4	0.5	....
SOLIDS: p.p.m.						
Total suspended p.p.m.	103	89	93	92	118	....
Settling in 2 hr. p.p.m.	....	....	....	....	....	....
Colloidal p.p.m.	....	....	....	....	....	....
Volatile p.p.m.	81	69	76	78	95	....
Volatile settling in 2 hr. p.p.m.	....	....	....	....	....	....
Volatile colloidal p.p.m.	....	....	....	....	....	....
OXYGEN CONSUMED:						
Unfiltered p.p.m.	50	51	48	50	64	....
Filtered p.p.m.	40	41	35	35	43	....
Retention hr.	2	2	2	2	2	....

	Apr.	May	June	July	Aug.	Sept.
Temp. degs. C.	....	....	....	....	....	....
Settled in cone c.c.	0.5	0.4	0.2	0.2	0.2	0.2
SOLIDS: p.p.m.						
Total suspended p.p.m.	131	113	108	100	96	103
Settling in 2 hr. p.p.m.	29	22	14	18	13	12
Colloidal p.p.m.	102	91	94	82	83	91
Volatile p.p.m.	108	93	88	77	78	84
Volatile settling, 2 hr. p.p.m.	23	16	11	12	8	6
Volatile colloidal p.p.m.	85	77	77	65	70	78
Oxygen demand p.p.m.	....	....	200	....	....	180
Retention hr.	2	2	2	2	2	2

TABLE XXI

Removals Effected by Tanks, 1914-1915.

Per Cent. of Reduction Effected

	Imhoff Tanks 1	2	3	Settling Tank 3
VOLUMETRIC:				
Solids settleable in Imhoff cone	62	64	78	80
GRAVIMETRIC:				
Total suspended solids	27	27	40	40
Total settleable solids	53	62	66	61
Total colloidal solids	26	12	21	21
Total volatile solids	31	31	46	40
Oxygen demand	29	34	41	20
Retention in tanks, hr.	2	2	2	2

TABLE XXII

Summary of Sludge Drying Data

	Imhoff Tanks 1	2	3	Separate Dig. Tank
	%	%	%	%
Moisture before drying	91.1	91.1	93.3	94.6
Moisture after drying	67.8	66.2	69.7	64.1
Volatile solids	45.5	46.5	46.7	36.6
Average depth on beds, inches	9.	9.	9	10
Average number of days drying	7.1	7.3	7.1	7.3

The Riensch-Wurl Screens.

The fine screens from which the data following were obtained are two in number, of the Riensch-Wurl design, installed at the 26th ward treatment plant as a permanent part of that plant. They were completed and commenced operation early in 1916 and since then have been in service.

The Riensch-Wurl screen consists principally of a disc of perforated metal plate, built in sections on a steel frame, with the frustum of a cone built up from its center, the whole being mounted on a shaft whose inclination from the vertical causes the disc to tilt at an angle with the horizon. A close seal is provided between the outer edge of the rotating disc and the stationary setting in which it is placed. To secure this a Z-bar is embedded in the masonry with one of its flanges exactly in the plane of the top of the rim of the frame or setting. The Z-bar carries on its top a large number of small segments, which can be moved in and out, so that the distance between their edges and that of the disc is not greater than the width of the slits or apertures in the disc. When these segments are adjusted, they are held in position by bolts.

The plane of the disc as designed in the Brooklyn screens is inclined 25 degrees with the horizon, and about 2/3 of its surface is submerged in the sewage, while the other 1/3 is above the sewage surface. As the disc revolves, the screenings are brought above the sewage and remove by means of revolving brushes carried at the ends of the arms of a large spider. The brushes revolve, as well as the arms and the disc, and the combined result is that every portion of the surface of the screen is brushed over at least twice during each revolution of the disc; except that the conical portion, which is cleaned by means of a vertical brush, gets but one brushing.

The design of the plant provides for a by-pass between the screens so that they may be operated individually or in series, and double screening tried out. Double screening did not prove to be advantageous. The screens are fourteen feet in diameter and operated by steam-engine drive.

The contract provided that the apertures or slits thru which the screening is effected, should be made of such size as might be found on trial to give the best results with the average flow of sewage at this location. Screening practice and experience elsewhere indicated that this should be determined experimentally, and with this end in view the specifications provided that four complete sets of screen-surface plates be supplied, as follows: The first cut with apertures 5/64-inch wide, the second with apertures 1/16-inch wide, the third with apertures 3/64-inch wide, and the fourth with apertures 1/64-inch wide. In each set the apertures were two inches long and staggered in the bronze

plate, which is ⅛-inch thick, each aperture having a countersunk cross-section, with the narrow part of the opening on the face of the screen. The 1/64-inch proved too fine and was soon recut to 1/32 inch.

These sets of screen plates were mounted on the screen frames successively, and tried out, and the aperture dimension 1/16-inch, which was decided to be the most suitable for screening the sewage at this plant, was selected for permanent installation. The plates not selected remained the property of the contractor.

It was provided that the size and number of apertures must be such that 6,000,000 gallons of sewage would pass thru the screen in 24 hours, the difference of head of sewage entering and leaving being not more than 12 inches, and that the screen must remove from the sewage practically all particles of suspended matter with a diameter 50 per cent. greater than the cross-section of the aperture.

The screens were supplied by the Sanitation Corporation of New York, and the design for placing them was made by the engineers of that corporation. In designing the plant, the Bureau of Sewers made provision for the installation of the screens in accordance with the design supplied. The screens were guaranteed for one year of service, at the end of which they should be in perfect repair, when taken over by the city. No requirement was made as to the amount, or per cent., of removal which should be made from the sewage, as it was believed that however little or much this might prove to be, the screens were necessary to help out the existing sewage treatment plant, then attempting to treat four times more sewage than it could fairly take care of. As it was not known what fineness of screens was best for local conditions, this was made the subject of experiment as already mentioned. The experimental work was placed in charge of the experiment station.

In designing sewage-screening plants, one has but little information to go on. Data are as yet very meager. Sewages differ very widely in the character of suspended solids, and naturally the kind of screens which will serve best with a given sewage, and the required fineness of the screening surface, vary widely. In Dresden, Germany, where there are four large screens of the Riensch-Wurl design, the breadth of the apertures is 2 m.m., which is found at that place to give a sufficient removal of suspended matter, and this is the only treatment found necessary for the sewage of that city, which, after screening, is discharged thru multiple outlets directly into the Elbe River, apparently affording a satisfactory disposal of sewage. Dresden has a population of between 400,000 and 500,000, and at its lowest stages the river is comparatively a small stream. The writer was told in Dresden that slits or apertures of less width than 2 m.m. reduce the capacity of the screens without much added advantage.

This is especially the case where, from the nature of the suspended matter, a mat tends to form over the screen surface and produce a straining effect. In Dresden the difference of head thru the screens varies from 2 to 6 c. m., under ordinary conditions, but at times is much greater than the larger figure—possibly four times as much.

The two Brooklyn screens were installed early in April, 1916. The north screen was equipped at this time with screen plates perforated with slits 2 inches long and 5/64-inch wide. The south screen was equipped with plates with slits 2 inches long and 1/16-inch wide.

The following tables give the results obtained at this time on dry weather flow sewage on the official test:

TABLE XXIII

Operation of Riensch-Wurl Screens

April-May, 1916

Capacity and Head Developed

Screen	Slit inches	Sewage Screened in 24 hrs.—gals.	Average Loss of Head at Screen—inches
North	5/64	8,077,851	0.118
South	1/16	8,204,113	0.121

Removal Effected as Shown by Crude Sewage and Effluent

	Crude Sewage	Screen Effluent	Removal	
North Screen—	p.p.m.	p.p.m.	p.p.m.	%
Suspended solids	159	137	22	14.0
Settling solids	75	60	15	20.
Non-settling	84	77	7	8.7
South Screen—				
Suspended solids	193	158	35	18.0
Settling solids	109.5	79.5	30	27.4
Non-settling	83.5	78.5	5	6.0

The screens continued in operation with 5/64-inch and 4/64-inch slits until the spring of 1917.

The following table gives a fair picture of the operation of the screens in comparison with the Imhoff tanks. The data are averages from all of the tanks taken together, and of both screens averaged. The crude-sewage influents are also averaged. The table includes dry weather flow only, storm water data as far as possible are excluded, and also all abnormal data. Screen removal was at times subject to wide variations and to extremes, these are excluded as far as possible.

TABLE XXIV

	Sewage Inf't.	Imhoff Tanks Eff't.	% Red.	R. W. Screens Eff't.	% Red.
Solids, by cone, c.c.l.	1.8	0.6	66	0.9	50
Solids, susp. tot. p.p.m.	171.	103.	40	137	20
Solids, settlings p.p.m.	61	29	52	45	26
Solids, colloid p.p.m.	110	81	26	98	11
Solids, volatile p.p.m.	133	82	39	107	19
Solids, vol. settling p.p.m.	41	17	59	....	....
Solids, vol. colloid p.p.m.	92	73	21	....	....
Oxygen demand p.p.m.	259	152	41	182	30

Theoretic retention, all tanks, 2 hours.
Sewage passing tanks per day:

Tank 1	145,000 gallons
Tank 2	100,000 "
Tank 3	50,000 "
	295,000 gallons

Sewage screened (both screens)	12 Mgd.
North screen	5/64 in. aperture
South screen	4/64 in. aperture
Screenings removed (both screens)	14.75 cu. ft. per Mg.
Weight per cu. ft.	72 lbs.
Moisture	81 %

In preparing the above table much discrimination has been called for, that the presentation might be fair. Storm removals often go above 50 per cent of the suspensa. Dry weather removal sometimes falls nearly to 0. These extremes mislead. Average performance has been sought for. To obtain, as well as select these data has been very difficult.

To include the abnormal is to render all conclusions useless. It should be remembered that screens always remove the screenable solids,—if these are absent they remove 100 per cent. of nothing.

In 1917 the following changes were made in the screens: The north screen was changed to a screening surface with apertures 3/64-inch wide, and the south screen to a surface with apertures 1/32-inch wide. In both cases the apertures were 2 inches long.

The weather was very unfavorable for making observations on screening dry weather flow, on account of the prevalence of frequent rainy days and showers. The screens were designed for receiving both dry-weather flow and storm water. It was difficult to obtain satisfactory data on dry-weather flow, and many obtained were useless on account of storm interference.

A remarkable difference was observed in the dry-weather sewage discharged into the quieting tank, from which the Imhoff tanks were supplied, and that which entered the screens. To study this phenomenon occupied several weeks of valuable time. Meanwhile the screens operated on a very weak sewage. Unfortunately the sewer and grit chamber could not be properly examined for obstructions without cutting off the sewage supply to the experimental plant, and as the flow to the Imhoff tanks was normal in quality it was decided not to do this until the July-August-September series of tests were compiled. In the

latter part of September the pumps were stopped and the sewer and grit chamber cleaned; an obstruction was then found, made of tin cans, rags, sticks, stones, silt, etc., formed diagonally across the chamber above the entrances to the screens, where it had acted as a submerged weir, interfering greatly with the dry-weather flow to the screens, but not at all with the flow to the by-pass from which sewage was obtained for the tanks. This did not much interfere with the storm water flow, which readily passed over it.

The screen data for this period are of value only as showing what removal might be expected from a very weak sewage,—from which much of the suspensa had settled. Under the conditions much more effect was produced on the sewage than would have been anticipated in advance.

TABLE XXV

Operation of Imhoff Tank 2, on Fairly Strong Sewage, and R. W. Screens on Abnormally Weak Sewage, Compared

Crude Sewage	Influent to Imhoff Tank 2	Influents to South Screen	Influents to North Screen
Temp. deg. C.	26.	26.	26.
Solids by cone c.c.l.	1.9	1.4	0.64
Solids susp. total p.p.m.	183	136	119
Solids volatile p.p.m.	143	106	92
Solids mineral p.p.m.	40	30	27
Dissolved oxygen p.p.m.	0.5	1.0	1.0
Oxygen demand p.p.m.	245	137	110
Filtered p.p.m.	144.	112	88

Effluents	Effluent Imhoff Tank 2		Effluent R. W. Screens South 1/32″		Effluent R. W. Screens North 3/64″	
Tank retention, 2 hr.		% Red		% Red		% Red
Solids by cone c.c.l.	1.1	44	1.2	14	0.5	22
Solids susp. total p.p.m.	138.	25	133	2	117	2
Solids volatile p.p.m.	109	24	108	....	92	0
Solids mineral p.p.m.	30	25	25	18	25	4
Dissolved oxygen p.p.m.	0	....	1	0	1	0
Oxygen demand p.p.m.	198	15	126	8	90	18
Filtered p.p.m.	119	17	77	31	65	26

	South Screen	North Screen
Sewage screened per diem	6.4 Mgd.	8.4 Mgd.
Average amount of screenings per diem	13.2 cu. ft.	13.9 cu. ft.
Average amount of screenings per mg	2.06 cu. ft.	1.65 cu. ft.
Average weight of screenings per cu. ft. Computed from averages	72 lbs.	72 lbs.

It will be noted that the sewage entering the screens was in nearly every item of its constituents weaker than the effluent leaving the Imhoff tank. It may be presumed, perhaps, that had the effluent from the tank passed thru screens, it would have been improved. The volume of screenings removed from such a weak sewage is worthy of remark.

Unfortunately the screenings produced were not weighed. The weights given in the table are an average weight for similar screenings determined by a number of experiments.

After the sewers were cleaned out, the following data were obtained, the screens operating as above on dry weather sewage.

Imhoff tank 2 being also supplied with the same sewage, which was not as strong as the yearly average by about 10 per cent., but was not to be considered abnormal. It will be observed that while the screen improved its removal, the tank showed the effect of a weaker sewage:

TABLE XXVI

Oct.-Nov.-Dec., 1917

	Sewage Inf't.	Imhoff Tank 2, 2 Hrs. Retention: Eff't.	Rem'l.	% Red
Solids by cone c.c.l.	1.4	0.8	0.6	44
Solids susp. total p.p.m.	141	116	25	18
Solids volatile p.p.m.	118	98	20	17
Solids mineral p.p.m.	23	18	5	22

R. W. Screens

Sewage given above	South Screen 1/32″: Efft.	Rem'l.	% Red	North Screen 3/64″: Efft.	Rem'l.	% Red
Solids by cone c.c.l.	0.5	0.9	64	0.6	0.8	54
Solids susp. total p.p.m.	116	25	18	117	24	17
Solids volatile p.p.m.	93	25	21	94	24	20
Solids mineral p.p.m.	21	2	9	22	1	4
Sewage screened per diem		5 Mgd.			5 Mgd.	
Screenings per diem		54 cu. ft.			52 cu. ft.	
Weight per cu. ft.		73.7 lbs.			74.2 lbs.	

Screened sewage was applied to the trickling-filter beds during the period beginning July 1 and ending December 31, 1916, with the object of comparing the results obtained with those from Imhoff-tank effluent. The filter beds had been operated with Imhoff-tank effluent previously to receiving the screened sewage. They had been out of service during February and March, but at the time were in good condition tho they had not fully regained their purifying power. For this reason and in order that the effect of the Imhoff effluent might have time to pass off, the results of the first month of operation are not included in the table which follows:

TABLE XXVII

Trickling Filter No. 3, Operated on Riensch-Wurl Screen Effluent

Aug.-Sept.-Oct., 1916 Apertures 1/16 and 5/64-inch

	Sewage Screened Average	Effluent from Filter No. 3* Depth of Stone Medium: 4 ft.	6 ft.	7′3″	8′6″	10′	From Humus Tank
Temp. dègs. C.	......	19.4	18.7	18.5	17.7	18.0	18.4
Suspended solids,							
Total p.p.m.	153	92	86	84	114	114	26
Volatile p.p.m.	110	85	61	61	79	79	22
Diss. oxygen, p.p.m.	......	3.1	3.7	3.6	4.1	4.3	2.8
Per cent. of sat.	......	33	39	38	43	45	30
Relative stability,							
Unfiltered per cent.	......	37	95	93	97	99	100
Filtered per cent.	......	70	100	100	100	100	....
Oxygen dem. bioch.							
Unfiltered p.p.m.	129	72	40	44	40	43	23
Filtered	70	30	19	18	16	18	00
Nitrite nitrogen p.p.m.	......	1.6	2.6	3.0	3.4	3.0	3.2
Nitrate nitrogen p.p.m.	......	1.1	4.1	3.8	4.6	5.4	5.7
Oxidized nitrogen p.p.m.	......	2.7	6.7	6.8	8.0	8.4	8.9

* Rate of application 4 Mgd. per acre.
Size of filter medium 1¼ to 2½ inches.

The settled effluent from the 10-foot depth was uniformly stable, and the results on filtered samples from all other depths except the 4-foot indicated that after settling out the humus the effluent would be satisfactory.

The rates of operation on filters Nos. 1, 2, 3 were set at 4 mgd. per acre, filter No. 4 being kept at the rate of 2 mgd. These were the same rates as had been employed in 1915, and previously to applying the screened sewage, except that filter bed No. 1 was increased in an effort to test it to destruction as regards clogging.

There seemed no especial tendency to clog the beds. It was threatened on bed No. 1, but did not develop. The sewage applied to the filter beds was at all times fresher than Imhoff-tank effluent would have been. No unpleasant smells were at any time in evidence.

In the results obtained from the operation of the Riensch-Wurl screens at this station, it is to be observed that the average percentage removal of settling matter is low. When the sewage enters the screen chamber it comes in with a rush strong enough to force many of the finer particles thru the screen. These particles tend to settle behind the screen, but do not accumulate there, as they are carried away by the effluent. The samples for analysis taken from the effluent were obtained as it flows out into the channel leading to the measuring weir, and may have contained an undue proportion of the particles above mentioned. It is difficult to obtain a sample from the effluent which shall be as representative of the work done as a sample taken from the Imhoff-tank effluent would be. A good deal of solid matter which really is screenable as well as settleable and would be removed under proper conditions, is forced thru the screens by the high rate of approach.

A serious difficulty was experienced in obtaining reliable results on the work of the fine screens, due to the fineness of the analytical methods employed. It is obvious that a test for suspended solids by the Gooch-crucible method, or for settling matter by the Imhoff cone, cannot take into account the grosser particles of matter that may be present in the sewage, lest the results be totally incongruous. This is partly remedied, of course, by noting the time required to fill a bucket with screenings, and the volume of sewage observed. The bucket takes into account both the fine material and the coarser matter, but unfortunately there seems to be no rational way of crediting the screenings removed to the removal of total suspended solids. It sometimes happened that by the determinations according to Standard Methods, A. P. H. A., the effluent contained more suspended matter than the influent, notwithstanding the fact that the screen was removing 350 to 500 lbs. of screenings per million gallons. One is tempted to ask the question, after this experience, are our methods of determining suspended solids above improvement or criticism?

If we do not obtain correct data on the influent to the screens, obviously we do not for the tanks either. Some discussion on this point seems desirable.

Cleaning of the Screens

Twice a day, a jet of water from a hose was played on the revolving disc. The water struck the screen with considerable force, and the slits were thoroly cleaned thereby. This treatment was followed by pouring about four ounces of kerosene on each of the four revolving brushes. This application not only removed the grease from the brushes, but also from the screens. In this way it was possible to keep the screen clean and bright at all times.

Removal of Screenings

When a bucket was filled with screenings, it was removed and an empty bucket replaced. The time was recorded. In this way the time required for filling each bucket was obtained. The full bucket was hoisted by a pulley and emptied into a special car. The car was rolled to the dump about 50 yards away and emptied on steam ashes. During the summer this dump was sometimes offensive, and became infested with flies, but this could have been prevented at all times by applying a slight amount of lime and covering with a thin cover of soil which was purposely omitted at this time in order that the tendency to cause nuisance might be observed. With the coming of cooler weather, tendency to cause nuisance ended. When the screenings are dry, nuisance is practically absent. It is desirable to treat the screenings shortly after their removal, so that all nuisances will be avoided. Composting with ordinary earth has proved sufficient to prevent all nuisance. Artificial drying and incineration are recommended as a method of disposal.

Samples of the screenings were examined for moisture content, volatile matter and ash. The volatile matter and ash were determined on the dry specimen. Samples for analysis were collected in an 8½-inch porcelain dish, and the test for moisture content was made on a portion of this sample in a 4-inch evaporating dish. Care was taken to obtain as representative a sample as possible. The moisture determination was made by evaporating the water in a weighed sample on a water bath, for twenty hours. The sample was then further dried in a hot-air oven at 100 deg. C, for four hours more. The loss in weight was determined and the percentage of water calculated. The volatile matter was determined gravimetrically by igniting a carefully weighed portion, in a Wiesnegg muffle furnace, until the contents were at a red heat. The loss in weight gave the volatile matter, and the difference from the original weight gave the ash.

The following table gives the results of screenings from the south screen. Apertures 1/32-inch.

Analyses of Screenings

Date	Moisture Per Cent.	Volatile Matter Per Cent.	Ash Per Cent.
July 27, 1917	88.7	87.8	12.2
July 30, 1917	86.0	81.6	18.4
Aug. 1, 1917 (a)	59.0	67.0	33.0
Aug. 1, 1917 (b)	76.8	68.3	31.7
Aug. 7, 1917 (c)	66.4	82.0	18.0
Aug. 10, 1917	71.6	82.0	18.0
Aug. 15, 1917	87.3	74.8	25.2
Averages	83.4	81.6	18.4

The averages exclude the three special samples.
(a) Sample of storm screenings.
(b) Sample of screenings taken near the end of the storm of August 1.
(c) Sample taken after water in screenings had been permitted to drain off.
Time required for one complete revolution of screen 2.4 minutes. Time required for one complete revolution of brushes 7.5 seconds.

Results from the north screen follow. Apertures 3/64-inch.

Date	Moisture Per Cent.	Volatile Matter Per Cent.	Ash Per Cent.
Aug. 21, 1917	82.0	80.9	19.1
Aug. 23, 1917	80.0	77.4	22.6
Aug. 24, 1917	86.8	93.5	6.5
Aug. 27, 1917	89.5	95.6	4.4
Aug. 31, 1917	85.9	78.8	21.2
Sept. 5, 1917	89.0	90.5	9.5
Sept. 12, 1917	90.4	94.0	6.0
Averages	86.3	87.2	12.8

Time required for one complete revolution of screen 2.3 minutes.
Time required for one complete revolution of brushes 7.8 seconds.

It will be seen from this table that the water content of screenings is generally high. Another important fact is the relatively large amount of organic matter. The weight of the screenings varied from 64 to 80 lbs. per cu. ft. the average being about 72 lbs., which is rather high; this is probably due to the age and condition of the sewage, and considerable grit.

Storm Water Operation of R. W. Screens

It was evident on studying the data obtained that storms present such varied phenomena that averages were highly misleading. It was also obvious to the observers that the ordinary methods of sampling and examination by Gooch crucible, and even by the Imhoff cone, were of little or no value, as these could not possibly give any correct result when used on matters of such large size as the storm water brought down—such as tin cans, old shoes, rags in quantity, as well as all grades and sizes of suspended solids. It was concluded, and we believe correctly, that the best means of exhibiting storm-screen performance was to give the amount of screenings removed by the screen, and to state how many gallons of storm sewage carried one cubic foot of screenings.

The following tables are constructed on the principle just stated.

The first column gives the time at which a bucket holding 8.6 cu. ft. of wet screenings was filled, and replaced by an empty bucket.

Operation on dry-weather flow following the storm, is included for comparison.

The second column gives the time in minutes required to fill the bucket with screenings.

The third column gives the head lost by the flow in passing the screen, and the size of the screen apertures.

The fourth column gives the cubic feet of flow which has passed thru the screen and over the knife-edge weir, while the bucket was filling.

The fifth column gives the gallons of sewage needed to produce 1 cu. ft. of screenings.

The sixth column gives the volume of wet screenings in parts per million of the sewage out of which it was taken by the screens, regardless of its water content.

Other data are added below the table giving general results.

TABLE XXVIII

R. W. Screen, Typical Operation

North Screen, Apertures 5/64-inch
June 7, 1916, storm began 8:00 A. M., ended 11:00 P. M.

Time: Bucket Filled	Time: Required to Fill	5/64″ Slits Head Lost	Quantity Screened: Q. by Weir	Quantity Screened: to 1 cu. ft. Screenings	Wet Screenings to Volume of Sewage
hour	min.	in.	cu. ft.	gal.	p.p.m.
10:00 a. m.	120	0¼	62,640	54,450	137
11:00	60	¼	31,440	27,340	274
11:30	30	¼	15,780	13,720	544
12:00	30	¼	15,840	13,770	543
12:40 p. m.	40	½	20,600	17,910	412
1:30	50	½	25,100	21,830	334
2:10	40	½	19,040	16,560	452
3:30	80	½	36,400	31,670	236
4:45	75	½	33,750	29,380	255
6:35	110	½	49,973	43,500	172
8:00	85	½	39,474	43,050	215
9:50	110	½	53,570	46,550	161
11:00 end	70	½	37,310	32,480	230
Dry weather flow June 8					
6:00 a. m.	420	¼	194,880	169,546	44
8:15 p. m.	135	¼	63,640	55,366	135

Contents of bucket 8.60 cu. ft.

1. Storm operation, 15 hours:
   Storm-sewage screened, 440,917 cu. ft. equals 3,306,900 gals.
   Screenings removed, 13 buckets equals 111.8 cu. ft. equals 33.6 cu. ft. per mg.
   Minimum flow screened per cu. ft. of screenings, 13,720 gals.
   Average moisture of screenings during storm, 60 per cent.
   Volatile matter in dry solids, 70 per cent.; mineral, 30 per cent.
2. Dry weather operation, 9¼ hours:
   Dry-weather flow screened, 258,820 cu. ft. equals 1,940,000 gals.
   Screenings from dry weather flow, 17.2 cu. ft. equals 8.8 cu. ft. per mg.
   Average moisture dry weather flow screenings, 82 per cent.
   Volatile matter in dry solids, 83 per cent.; mineral, 17 per cent.

TABLE XXIX

R. W. Screen, Typical Operation

South Screen, Apertures 4/64-inch July 25, 26, 1916. See data below

Time Bucket Filled	Required to Fill	4/64″ Slits Head Lost	Quantity Screened Q. by Weir	Quantity Screened to 1 cu. ft. Screenings	Wet Screenings to Volume of Sewage
hour	min.	in.	cu. ft.	gal.	p.p.m.
July 25 7:00 a. m.		Storm flow			
9:00	120	0.½	89,100	77,600	97
1:00 p. m.	240	½	168,000	146,000	51
3:30 p. m.	150	½	105,450	91,740	82
4:00	30	¾	22,560	19,600	380
4:30	30	¾	19,500	17,000	441
6:15 end	105	¾	65,100	56,800	132
		Dry weather flow			
11:00 p. m.	285	½	213,750	186,000	40
July 26 4:20 a. m.	320	½	208,000	181,000	41
8:30	250	½	160,100	139,200	54
11:30 end	180	½	108,000	94,000	80
		Storm flow			
1:00 p. m.	90	½	50,200	43,700	171
1:15 p. m.	15	¾	8,360	7,265	1,030
1:30 end	15	¾	8,360	7,265	1,030
		Dry weather flow			
9:00 p. m.	450	½	312,200	271,700	28
11:00 p. m.	120	½	99,600	86,600	86
July 27 1:20 a. m.	140	½	116,200	101,200	74
3:00 a. m.	100	½	55,800	49,550	154
8:30 a. m.	270	½	175,500	152,600	49

Contents of bucket 8.60 cu. ft.

1. Storm operation, 13¼ hours:
   Storm-sewage screened, 436,699 cu. ft. equals 4,025,000 gals.
   Screenings removed, 9 buckets equals 77.4 cu. ft. equals 19.2 cu. ft. per mg.
   Minimum flow screened per cu. ft. of screenings, 7,265 gals.
   Average moisture of screenings during storm, 63 per cent.
   Volatile matter in dry solids, 73 per cent.; mineral, 27 per cent.
2. Dry weather operation, 35¼ hours:
   Dry weather flow screened, 1,449,150 cu. ft. equals 10,868,000 gals.
   Screenings removed, 9 buckets equals 77.4 cu. ft. equals 7.5 cu. ft. per mg.
   Average moisture, dry weather screenings, 80 per cent.
   Volatile matter in dry solids, 81 per cent.; mineral, 19 per cent.

TABLE XXX

R. W. Screen, Typical Operation

North Screen, Apertures 3/64-inch
August 24, 1917, storm began 1:20 P. M., ended 8:24 P. M.

Time Bucket Filled	Required to Fill	3/64″ Slits Head Lost	Quantity Screened Q. by Weir	Quantity Screened to 1 cu. ft. Screenings	Wet Screenings to Volume of Sewage
hour	min.	in.	cu. ft.	gal.	p.p.m.
1:35 p. m.	15	1¾	6,264	5,450	1,372
2:00	25	1	10,440	9,080	826
5:10	190	¾	79,344	69,000	108
6:10	60	½	24,056	20,900	358
6:50	40	¾	16,724	14,550	514
7:40	50	½	20,880	18,150	414
8:25 end	45	½	18,792	16,350	457
Aug. 25		Dry weather flow			
12:25 a. m.	240	½	100,224	87,300	86
9:00	515	½	215,064	187,100	40
8:30 p. m.	690	½	288,144	250,900	30

Contents of bucket 8.60 cu. ft.

1. Storm operation, 7 hours, 5 minutes:
   Storm-sewage screened, 176,500 cu. ft. equals 1,323,700 gals.
   Screenings removed, 7 buckets equals 60.2 cu. ft. equals 46.3 cu. ft. per mg.
   Minimum flow screened per cu. ft. of screenings, 5,450 gals.
   Average moisture of screenings during storm, 83 per cent.
   Volatile matter in dry solids, 87.5 per cent.; mineral, 12.5 per cent.
2. Dry weather operation, 24 hours, 5 minutes:
   Dry weather flow screened, 603,432 cu. ft. equals 4,525,700 gals.
   Screenings removed, 3 buckets equals 25.8 cu. ft. equals 5.7 cu. ft. per mg.
   Average moisture of dry weather screenings, 86.8 per cent.
   Volatile matter in dry solids, 93.5 per cent.; mineral, 1.5 per cent.

TABLE XXXI

R. W. Screen, Typical Operation

South Screen, Apertures 2/64-inch

August 1, 1917, storm began 11:35 A. M., ended 8:10 P. M

Time: Bucket Filled	Time: Required to Fill	2/64″ Slits Head Lost	Quantity Screened: Q. by Weir	Quantity Screened: to 1 cu. ft. Screenings	Wet Screenings to Volume of Sewage
hour	min.	in.	cu. ft.	gal.	p.p.m.
11:50 a. m.	17	2.	6,925	6,020	1,243
12:50 p. m.	60	0.¾	20,904	18,200	412
3:00	130	½	36,270	31,550	237
4:10	70	½	3,255	2,930	2,641
4:45	35	¾	3,255	2,930	2,641
5:30	45	¾	6,300	5,440	1,365
8:10 end	150	½	27,900	24,300	309
Aug. 2		Dry weather flow			
7:45 a. m.	705	½	278,400	242,000	31
11:45 a. m.	240	½	94,800	82,430	91
11:45 p. m.	720	½	284,500	247,500	30

Contents of bucket 8.60 cu. ft.

1. Storm operation, 8½ hours:
   Storm-sewage screened, 104,809 cu. ft. equals 786,000 gals.
   Screenings removed, 7 buckets equals 60.2 cu. ft. equals 76.6 cu. ft. per mg.
   Minimum flow screened per cu. ft. of screenings, 2,930 gals.
   Average moisture of screenings during storm, 59 per cent.
   Volatile matter in dry solids, 67 per cent.; mineral, 33 per cent.
2. Dry weather operation, 27¾ hours:
   Dry weather flow screened, 657,700 cu. ft. equals 4,932,700 gals.
   Screenings from dry weather flow, 25.8 cu. ft. equals 5.2 cu. ft. per mg.
   Average moisture, dry weather screenings, 77 per cent.
   Volatile matter in dry solids, 68 per cent.; mineral, 32 per cent.

Sewage Treatment by Oxidation

So much space and time have been taken in the presentation of sewage data, and methods of removing suspended solids from sewage, that the subject of oxidation of sewage must be eliminated altogether, or given very little space. To cut it out entirely would be to leave the other data presented incomplete, as it is very desirable to observe the effect of tank treatment and fine-screen treatment, from the standpoint of the trickling filter bed. All that can be attempted, however, will be to give some space to this subject for that purpose. The treatment of sewage by oxidation was by far the most extensive and, perhaps, the most important work done at the Brooklyn experiment station. The results of these studies cannot be presented in a limited space or at this time. But if the official report of the work is not published before the next annual convention of this Society, the writer will arrange, if possible, to make it the subject of a paper. Under this head must also be included the treatment of sewage by aeration and activation, both having been given extensive study at the station, but which on account of lack of space cannot be included here.

The term "trickling filter" instead of "sprinkling filter" was adopted in conformity with the recommendation of the Committee on Nomenclature of the American Public Health Association.

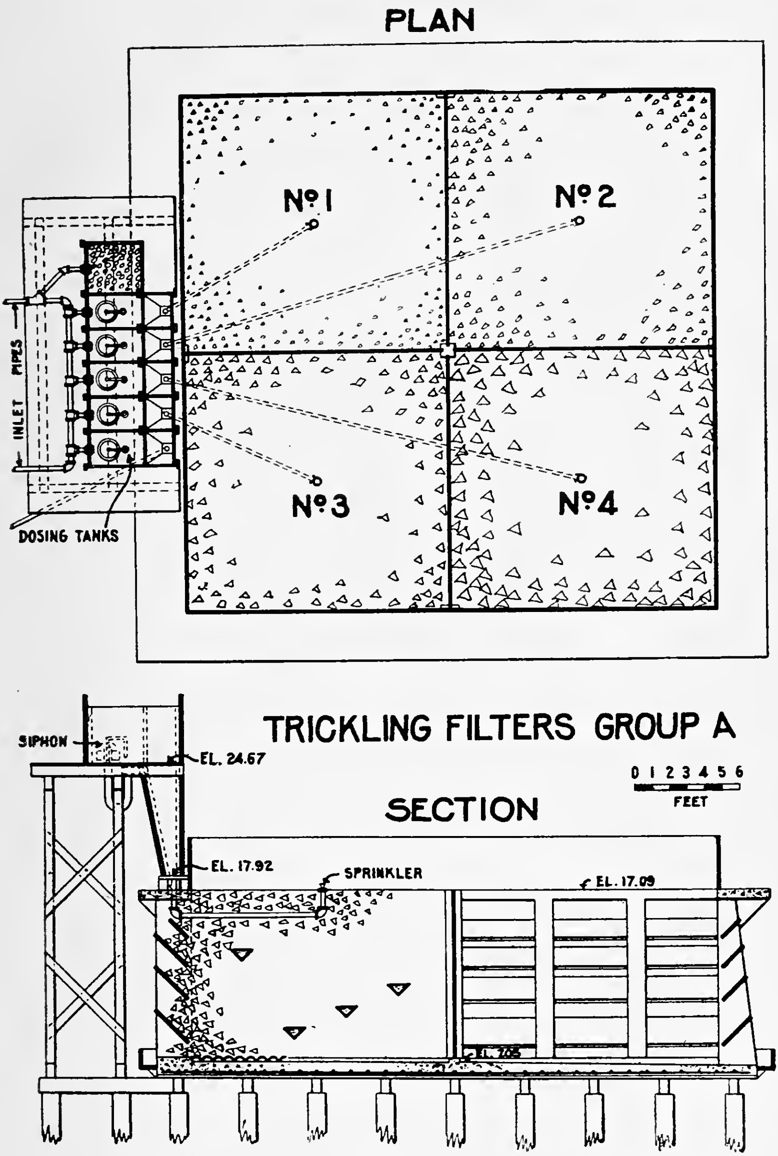

Fig. 17.

This is based on the essential features of the filter rather than on the method of application of the sewage, and therefore seems a logical term.

The trickling-filter beds were all supplied with sewage by means of dosing tanks.

Each dosing tank was provided with a 5-inch Miller siphon which discharged the dose into an inverted pyramidal feeding tank, from the bottom of which it was carried, by a pipe embedded in the medium, to the sprinkling nozzle, by which it was sprayed over the bed. These tanks and the inverted pyramidal feeding tanks into which they discharge were constructed of yellow pine.

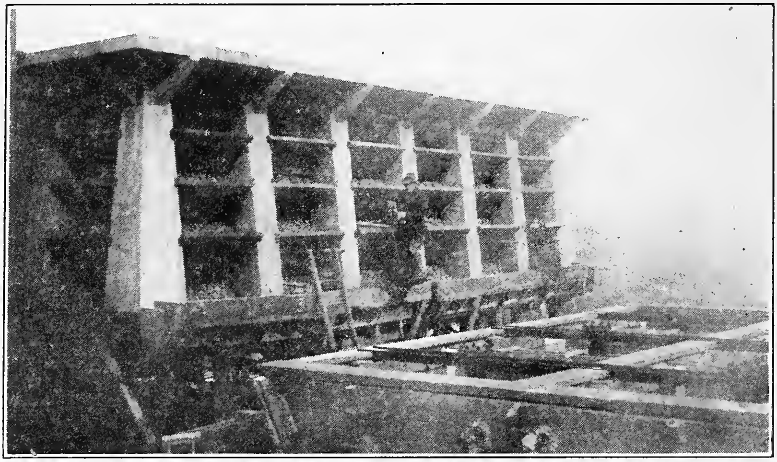

Fig. 18. Trickling Filters.

The elevation of the dosing-tank water line at the instant of siphon discharge was 26.74 feet. The water-line in the inverted pyramidal feeding tanks was controlled by the amount of sewage discharged from the dosing tanks, and its maximum elevation with the largest dose that could be discharged was 23.50 feet, which was 6 ft. 2 in. above the surface of the beds. This head could be varied by a movable bulkhead placed in the dosing tank, which increased the number of doses per hour.

As the bulkhead was moved toward the siphon the effective capacity of the tank was diminished. In the upper part of the bulkhead were placed circular orifices cut in thin sheet copper, each of which delivered half a million gallons per acre daily on the beds, under a head held constant by means of an adjustable outlet pipe. By stopping an appropriate number of these orifices with corks the rate on the filters was maintained as desired. These orifices were subject to hourly inspection and did not show any tendency to clog with Imhoff effluent. Their accuracy could at any time be checked by calibration in the dosing tank, and this was frequently done.

Description of Filters

There were two groups of trickling filter beds which have been indicated as Group A and Group B. Each will be described separately.

Group A consisted of the ordinary type of trickling filters. There were four beds. The foundations were carried on piles, and the bottoms of the beds were 6 feet above the level of the marshland over which they were built. High water at unusually high tides washed underneath, at times covering the marsh to a depth of 6 or 8 inches. Each bed was square and had an effective area of .005 of an acre.

Partitions, 4 inches thick, were carried from the floor to the surface of the medium between adjacent beds.

The outer walls of the beds were formed by means of reinforced concrete piers, carrying a slab coping of reinforced concrete at the tip. The piers were cast with slots for receiving 3-inch yellow-pine slabs or shutters, which were set at an angle of 45 degrees, sloping inward, spaced 2 feet apart, against which the medium rested, affording a maximum admission for air and preventing the escape of sewage.

The floor was formed of concrete with a slight slope to the outlet of the underdrains. Half-tile, 6 inches in diameter, were laid with the convex sides up on the concrete floor to afford drainage; the effluent flowing to gutters or troughs placed around the bottom of the beds, outside of the wall piers. Each bed had its individual gutter, which discharged by means of a pipe or flume to its individual secondary settling tank.

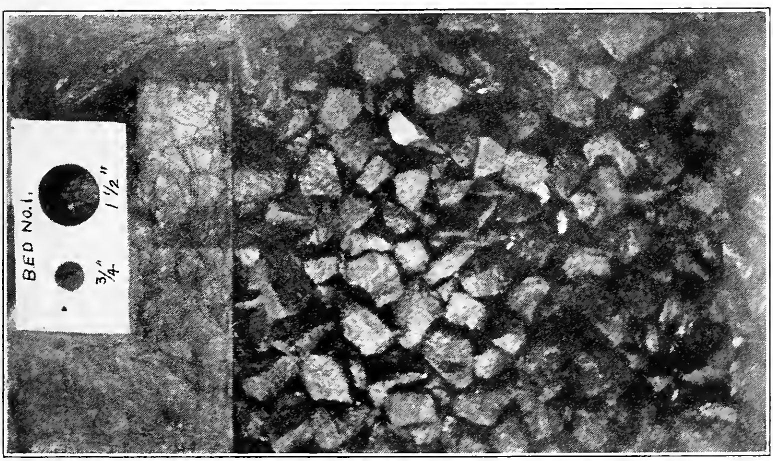

Fig. 19. Trickling Filter Bed, after Two Years' Service.

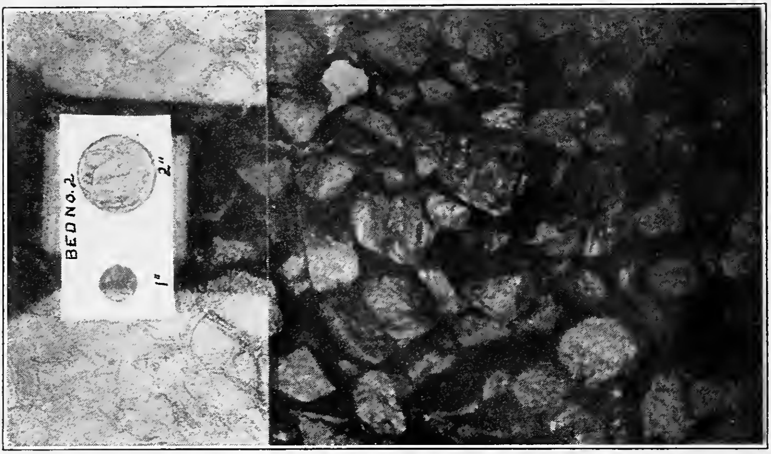

Fig. 20. Trickling Filter Bed after Two Years' Service.

The medium was 10 feet in depth over the top of the underdrains, and of very carefully selected broken trap-rock, many runs thru screens having been necessary to obtain the result required.

In order to prevent the effects of wind on the sewage distribution, a shield was provided, consisting of a board fence at the surface carried between the beds and around them.

In order that the effect of the depth of filter medium under similar conditions of operation might be obtained, test trays were placed in the filter beds at different depths. The trays were so placed that samples could be taken at depths from the surface of 4 feet, 6 feet, 7 feet 3 inches, and 8 feet 6 inches. Samples taken from the bottom of the bed give the result of 10 feet depth.

For the distribution of sewage to the surface of the filter, several types of nozzles were tried, but for the majority of the experiments, which were at high rates, the Taylor square spray and the Worcester nozzles were employed.

Size of Medium in Filter Beds, Group A

Bed No. 1, stone passing ring 1½ inches in diameter, retained by ¾-inch ring.

Bed No. 2, stone passing ring 2 inches in diameter, retained by 1-inch ring.

Bed No. 3, stone passing ring 2½ inches in diameter, retained by 1¼-inch ring.

Bed No. 4, stone passing ring 2½ inches in diameter, retained by 1¾-inch ring.

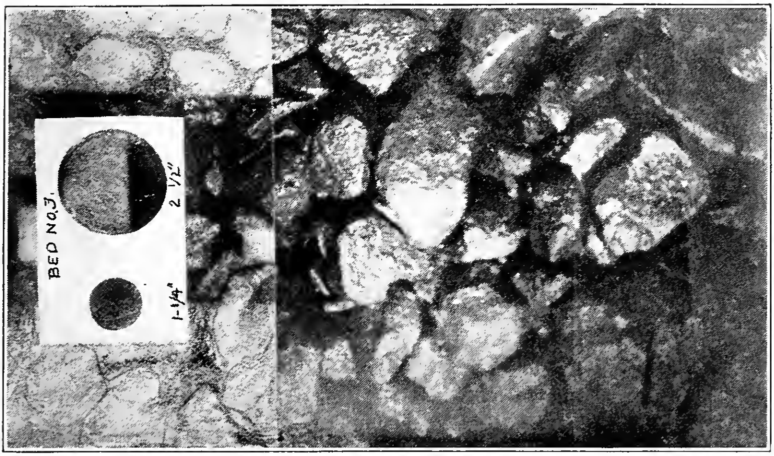

Fig. 21. Trickling Filter Bed after Two Years' Service.

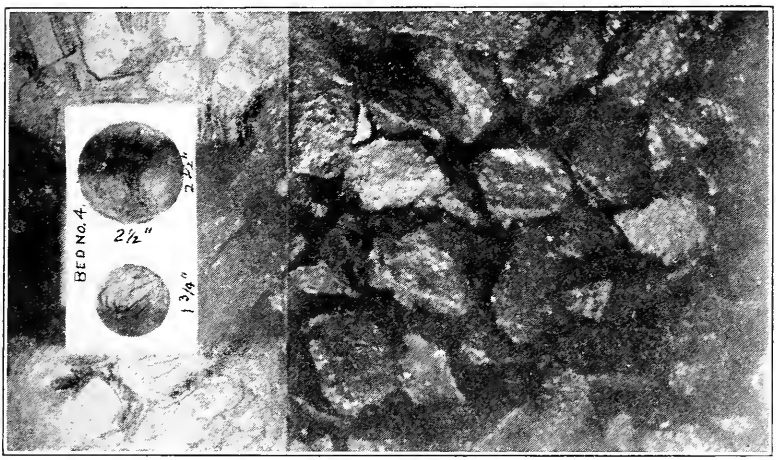

Fig. 22. Trickling Filter Bed after Two Years' Service.

Group B was a tank 12 feet in diameter and 16 feet high in which were placed two beds. A partition wall divided the tank into two equal parts and each side was filled with stone filtering medium to the same depths. The bottom of each side was underdrained with 6-inch half-pipe tile, on a concrete bed, and closed from external air by the tank walls. Each side was kept entirely from the other, and drained independently to a secondary tank. Each side was provided with a grid for supplying compressed air, placed within the medium near the bottom, formed of ¾-inch

iron pipe, perforated every 6 inches with ⅛-inch holes, thru which compressed air could be supplied.

In operation the sewage was sprayed upon the surface by a single nozzle placed at the center of the two beds, over the dividing wall between them. Two designs of Taylor circular-spray nozzles, and the Worcester nozzle, were tried during the course of the experiments. Both beds could be operated as ordinary trickling filter beds, in which case air entered the bed from the surface only. Compressed air could be supplied to both beds at the same time, or one side could be operating as an ordinary trickling filter, while the other was operated as a trickling filter with compressed air added in the bed, in order that the effluents might be compared, and the effect of the added air observed. The filtering medium was of the best selected broken trap-rock. The depth of the medium was 10 feet, and might be increased up to 16 feet, if desired.

Fig. 23. Surface of Trickling Filter 3, after Six Months' Service on Screened Sewage.

Size of Medium in Filter Beds, Group B

Bed No. 5, stone passing ring 2½ inches in diameter, retained by 1¼-inch ring.

Bed No. 6, stone passing ring 2½ inches in diameter, retained by 1¼-inch ring.

Size and Character of Stone for Trickling Filters

Every effort was made to obtain an accurate knowledge of the stone which was put into the filters. To this end, very frequent samples were taken during the delivery of the material at the

plant, and all stone which did not conform very closely to the provisions of the specifications were rejected and the contractor was required to re-screen it.

The specifications for filter No. 4, calling for stone from 2-inch to 2½-inch size, were found too severe, when the effort was made to screen the stone to the specified size; so, after many unsuccessful attempts, the contractor was allowed to furnish stone which would pass a 2½-inch ring and be retained upon 1¾-inch ring.

The following table shows the percentage by weight of the stone in each filter which did not lie within the specified limits:

Filter No. 1	4.7%
Filter No. 2	6.3%
Filter No. 3, 5, 6	2.3%
Filter No. 4	3.7%

The data obtained by analyses of samples were as follows: (1) median size, (2) uniformity number, (3) superficial area, and (4) per cent. of voids.

The "median size" is a number somewhat analogous to the "effective size" of filter sand, but is defined as follows: it is the diameter of a ring of such size that fifty per cent. (by number) of the stones will be retained upon it and fifty per cent. pass it. It is generally not much different from the mean of the diameters of the rings defining the sample in the specifications. The "uniformity number" is analogous to the "uniformity coefficient" used in water filter sand, and is the ratio of the diameter of the ring thru which 75 per cent. (by number) of the stones will pass to that of the ring thru which 25 per cent. will pass. It approaches 1.00 as the material approaches perfect uniformity, and increases with the non-uniformity of the sample. The per cent. of voids was determined by weighing the water necessary to fill the void spaces in an amount of stone whose gross volume was known.

TABLE XXXII

Properties of Broken Trap Rock For Use in Filters

	Filter 1	Filter 2	Filters 3, 5, 6	Filter 4
Specified size (inches)	1½-¾	2-1	2½-1¼	2½-1¾
Median size (inches)	.94	1.32	1.83	2.14
Uniformity number	1.50	1.56	1.42	1.20
Superficial area per ton (sq. ft.)	1025	711	568	465
Superficial area per cu. yd. (sq. ft.)	1343	945	741	579
Per cent. void space	46.8	45.0	46.5	47.0

On examining the above table, it will be noted that the superficial area is roughly proportioned to the reciprocal of the median size. This would, of course, be strictly true, if the material consisted of uniform spheres.

The most uniform sample (filter No. 4) has the highest percentage of voids, and the least uniform (filter No. 2) has the lowest percentage, which is also what should be expected.

Determination of Stone Surfaces

Since the degree of purification obtained in a trickling filter is dependent, among other factors, upon the number of bacteria which can act upon the sewage, and the number upon the amount of surface upon which they can multiply, a knowledge of the superficial area of the stone. per ton or per cubic yard is desirable. Hitherto, so far as the writer's knowledge goes, no one has published any data upon this subject, and an attempt was made here to arrive at knowledge of it, and the laws of its variation.

The method employed to obtain this information was as follows: Samples of broken granite and of broken trap were obtained and screened thru sieves having rings of the following diameters: 2½", 1¼", 1", ¾", ½". About 100 stones of each size were kept for area and weight determination. The area was determined by tracing with a sharp pencil the shapes of the faces of the stones on a sheet of paper. As the faces of the stones are almost always nearly plane, this presented no serious difficulty, aside from extreme laboriousness. The areas were then determined by planimeter.

To enable the information to be applied to the various sizes of stone, as put into the filters, the ratio of the mean area to the area of a sphere. of the same material of equal weight (or equivalent sphere), seemed the easiest to use. The following table gives the results of the study:

TABLE XXXIII

Analyses of Stone for Trickling Filter Beds

		Weight		Surface		
Sizes Inches	Pieces in sample	Total grams	Average grams	Total sq. ft.	Average sq. ft.	Ratio of mean surf. to surf. of equiv. sphere
¾-½						
Granite	100	265	2.65	.561	.0056	1.08
Trap	100	415	4.15	.881	.0088	1.12
1-¾						
Granite	102	630	6.18	1.049	.0103	1.12
Trap	100	829	8.29	1.423	.0142	1.30
1¼-1						
Granite	98	1320	13.46	2.115	.0216	1.40
2½-1¼						
Trap	100	1855	18.55	2.428	.0243	1.29
Granite	108	7289	67.50	6.049	.0560	1.24
Trap	100	6330	63.30	5.015	.0502	1.18

The filter beds were made of trap rock exclusively. In the above table, results of analyses from granite samples are included for comparison.

Observation of the samples shows that among the pieces there are a greater or less number of stones which are "scales" or "plates", whose thickness is small compared with the other di-

mensions. The relatively high values of the above ratio in the sizes from ¾″ to 1¼″ indicate a rather high proportion of these thin stones in the above mentioned sizes.

As the stone for the filters was delivered, samples were taken and screened by sieves of plate containing circular holes having diameter varying by ¼″. The total weight of a size of separation divided by the number of stones, gives the mean weight, from which the area of the equivalent sphere may be found from the following formula:

$$A = \sqrt[3]{\frac{36 \ 3.1416 \ W^2}{g^2}} \times .0010765$$

in which A is area of equivalent sphere in square feet; W, the mean weight of a single stone is grams; g, the specific gravity of the rock; and .0010764 the constant for reducing sq. cm. to sq. ft. A suitable multiplier selected from the following table enabled the true mean superficial area corresponding to the mean weight to be calculated.

TABLE XXXIV

Mean weight Grams	Ratio of mean area to area of equiv. sphere
4	1.12
5	1.15
6	1.20
7	1.25
8	1.29
9 to 20	1.29
25	1.27
30	1.26
35	1.25
40	1.24
45	1.22
50	1.21
55	1.20
60	1.19
80	1.18
100	1.17
120	1.15
140	1.14
160	1.13
180	1.12
200	1.10
220	1.09

This table of multipliers was interpolated from the data in the first table, and from an area determination performed subsequent to the first studies. The first table carried the knowledge of the ratio only to a mean weight of 60 grams, and the subsequent determination enabled it to be known when the mean weight was 225 grams.

Having the mean area of a single stone and the number of stones of that separation size in the sample, it is simple to compute the total area per ton, and after weighing a known volume of the sample, to compute the total area per cubic yard, as put into the filter.

TABLE XXXV

Summary of Results.

Crude Sewage,—Imhoff Tanks 1 and 2, Average,—Trickling Filters 1-2-4 Depth, 6 ft.—Filters 5 and 6, Depth 10 ft.

	Crude Sewage				Imhoff Tanks 1 & 2				Trick'g. Filt. 1				Trick'g. Filt. 2				Trick'g. Filt. 4				Trick'g. Filt. 5				Trick'g. Filt. 6				5 & 6
1915	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Av.
Tot. susp. solids	197	192	180	189	145	140	141	142	78	126	69	91	76	61	81	73	92	120	72	95	78	65	81	75	75	74	82	77	76
Vol. " "	149	142	139	143	115	108	113	112	53	83	46	61	52	47	57	52	65	82	52	67	55	51	56	54	53	51	58	54	54
Temperature	15.7	18.0	20.6	18.1	15.8	17.9	20.8	18.2	14.9	15.8	20.7	17.1	13.6	16.2	20.4	16.7	12.8	14.5	19.2	15.5	14.6	16.8	19.9	17.1	14.9	17.2	19.8	17.3	17.2
Diss.ox. p.p.m.	.7	1.7	1.0	1.1	.2	.3	0.0	.2	3.7	3.5	3.2	3.5	3.5	3.7	2.0	3.1	3.5	3.5	3.3	3.4	3.8	4.3	.31	3.7	3.6	4.1	3.6	3.8	3.7
" " % sat.	7	18	11	12	2	3	0	2	36	35	35	35	33	37	22	31	33	34	35	34	37	44	34	38	35	42	39	39	38
Rel. stability									100	100	100	100	76	100	100	92	39	90	88	72	100	100	100	100	100	100	100	100	100
" (paper-filt.)									100	100	100	100	100	100	100	100	83	100	100	94	100	100	100	100	100	100	100	100	100
Diss. ox. demand	270	211	230	237	218	198	191	202	28	33	22	28	69	23	52	48	79	57	54	63	42	26	42	37	42	20	25	29	33
" (filt.)									9	11	11	10	29	11	18	19	29	24	26	26	27	12	17	19	15	14	16	15	17
Nitrogen as																													
nitrites									1.1	1.1	2.4	1.5	.8	1.8	2.9	1.8	.7	2.0	2.6	1.8	1.1	1.0	2.2	1.4	1.5	2.2	2.3	2.0	1.7
nitrates									11.7	12.8	15.7	13.4	3 4	6.6	10.2	6.7	2.5	6.0	9.4	6.0	8.2	10.4	12.1	10.2	9.4	12.0	13.6	11.7	10.9
Daily rate per acre									2Mg.	2Mg.	2Mg.	2Mg.	4Mg.	4Mg.	4Mg.	4Mg.	2Mg.	2Mg.	2Mg.	2Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.
Size of Filter Medium (See also Table XXXII.)									1½ to 0¾ ins.				2 to 1 ins.				2½ to 1¾ ins.				2½ to 1¼ ins.				2½ to 1¼ ins.				

Trickling Filter 3, and Settling Tank, (Humus). All Depths.

Depth below surface of bed	4 ft.				6 ft.				7.25 ft.				8.50 ft.				10 ft.				Humus Tank 9			
1915	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.	Apr.	May	Jun.	Av.
Tot. susp. solids, p.p.m.	75	67	82	75	85	71	80	79	80	69	72	74	92	74	75	80	110	92	102	101	45	35	34	38
Vol. " "	53	48	61	54	61	50	57	56	57	49	51	52	66	51	52	56	69	63	66	66	34	27	24	28
Temp. C.	15.5	17.4	21.3	18.1	14.6	15.9	20.6	17.1	14.7	15.8	20.4	17.0	14.0	15.6	20.0	16.6	13.9	15.3	20.0	16.4	14.1	15.4	19.7	16.5
Diss. ox. p.p.m.	2.3	2.2	1.7	2.1	3.1	3.2	2.0	2.8	3.8	4.1	3.0	3.6	3.7	4.4	2.9	3.7	4.4	4.5	4.2	4.4	2.9	3.1	2.6	2.9
" " % sat.	23	23	19	22	30	31	22	28	37	41	33	37	36	44	32	37	42	45	46	44	28	31	28	29
Rel. Stability %	19	16	16	17	92	98	99	96	100	100	100	100	85	100	100	95	95	99	100	98	100	100	100	100
" (paper filt.)	24	27	35	29	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	.....	.....	.....	.....
Diss. ox., demand, p.p.m.	59	55	58	57	40	41	39	40	35	38	38	37	48	30	30	36	52	25	27	35	19	18	14	17
" (filtered)	43	38	39	40	20	18	18	18	22	18	20	20	18	18	15	17	15	12	11	13	.....	.....	.....	.....
Nitrogen as nitrites	0.5	0.2	0.4	0.4	1.5	1.6	2.7	1.9	1.4	1.7	1.9	1.7	1.1	1.6	2.4	1.7	1.2	1.0	1.6	1.3	1.5	2.0	2.2	1.9
" " nitrates	0.6	0.2	0.2	0.3	6.3	7.9	10.7	8.3	7.7	8.0	11.1	8.9	8.0	9 5	12.7	10.1	9.5	11.0	14.7	11.7	8.0	9.6	12.3	10.0
Daily rate per acre	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	.....	.....	.....	.....

For Crude Sewage and Imhoff Tank Data, see Table above.
Size of Filter Medium 2½ to 1¼ inches.
Humus Tank with 10 ft. depth only.

The following numerical example will illustrate. The screen analyses of the stone put into filters No. 3, 5 and 6 gave the follow data:

Size Passing	Retained by	Total Weight lbs.	No. Stones
2½	2	118.5	306
2	1¾	67.5	247
1¾	1½	23.2	145
1½	1¼	16.0	157
1¼	1	5.0	85
1	¾	.27	7

Beginning with the 2½—2 size, the mean weight of a single stone is $\frac{118.5 \times 454}{306} = 176$ grams. From the formula for surface-equivalent sphere, we find this weight corresponds to .0843 sq. ft. From the table of ratios, we find the proper multiplier for size 176 grams to be 1.12; hence the true mean area of a single stone is .0943 sq. ft. This multiplied by 306 gives 28.9 sq. ft. for the area of the stones of the sample lying between 2½" and 2". Proceeding in the same way, we find the total area of the size 2—1¾ to be 18.8 sq. ft.; of the size 1¾—1½ to be 8.0 sq. ft.; of the size 1½ to 1¼ to be 6.6 sq. ft.; of the size 1¼ to 1 to be 2.9 sq. ft.; and of the size 1—¾ to be 2 sq. ft., making a total area for the sample (which weighed 230.47 lbs.) of 65.4 sq. ft., or 568 sq. ft. per ton. It was found that the stone, as placed in the filter, weighed 1.305 tons per cubic yard, so that the area amounted to 741 sq. ft. per cubic yard.

Operation of Trickling Filters

Arrangement of the Beds and Final Settling Tanks:

Filter No. 1 Discharges thru Tank No. 6
Filter No. 2 Discharges thru Tank No. 10
Filter No. 3 Discharges thru Tank No. 9
Filter No. 4 Discharges thru Tank No. 7
Filter No. 5 Discharges thru Tank No. 5
Filter No. 6 Discharges thru Tank No. 8

Area of beds, Nos. 1 to 4, inclusive, .005 acre
Area of beds, Nos. 5 to 6, inclusive, .00127 acre

During the course of the experiments the sewage distributed on the trickling filters consisted of (1) Imhoff tank effluent; (2) crude sewage which had been subjected to fine screening. The former was experimented with from November 1, 1913, when the filters were first put into operation, to December 15, 1915. During the latter part of December, 1915, and during the winter and spring of 1916, the filters were shut down, pending the completion of the Riensch-Wurl screen plant. Crude sewage,

TABLE XXXVI

Summary of Results.

Crude Sewage, Imhoff Tanks 1 and 2, Av., Trickling Filters 1-2-4, Depth 6 ft.—Filters 5 and 6, Depth 10 ft.

	Crude Sewage				Imhoff Tanks 1 & 2				Trick'g. Filt. 1				Trick'g. Filt. 2				Trick'g. Filt. 4				Ttick'g. Filt. 5				Trick'g. Filt. 6				5 & 6
1915	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Jul	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Av.
Tot. susp. solids p.p.m.	147	135	205	163	145	107	122	125	63	36	29	43	67	58	48	58	68	60	60	63	75	62	58	65	80	56	53	63	64
Vol. susp. solids p.p.m.	103	102	164	123	107	82	97	95	44	23	23	30	46	39	35	40	47	41	43	44	53	44	44	47	55	41	39	45	46
Temp. C.	22.7	22.5	23.0	22.7	23.0	23.8	23.9	23.6	22.5	23.5	23.5	22.8	22.3	22.3	23.0	22.5	22.0	22.7	22.0	22.4	22.8	23.9	23.2	23.3	22.6	24.1	23.3	23.3	23.3
Diss. ox. p.p.m.	0.7	0.5	0.1	0.4	0.0	0.1	0.0	0.0	4.2	4.8	3.9	4.3	2.4	3.9	3.6	3.3	3.2	3.4	3.2	3.3	3.5	3.8	3.5	3.6	3.2	4.4	3.7	3.8	3.7
" " % sat.	8	6	1	5	0	1	0	0	48	56	45	50	27	44	41	37	36	39	36	37	40	44	40	41	36	52	43	43	42
Rel. stab. %									100	100	100	100	94	100	100	98	97	100	100	99	92	100	100	97	100	100	100	100	98
" " (paper filt.)									100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Ox. demand p.p.m.	173	216	305	231	166	137	233	179	24	.20	44	29	38	33	58	43	42	44	60	48	49	40	61	47	27	25	62	38	43
" " (paper filt.)									10	10	29	16	16	18	41	25	20	16	41	26	12	10	45	22	13	11	48	24	23
Nitrogen as																													
nitrites									2.3	2.2	2.2	2.2	3.2	2.6	2.3	2.7	3.5	2.1	1.7	2.4	2.7	2.4	1.8	2.3	2.3	2.4	2.7	2.5	24
nitrates									14.2	10.6	16.3	13.7	8.6	7.6	9.7	8.6	5.8	8.5	10.3	8.2	10.2	9.4	12 5	10.7	12.2	10.6	13.6	12.1	11.4
Daily rate per acre.									2Mg.	2Mg.	2Mg.	2M.g	4Mg.	4Mg.	4Mg.	4Mg.	2Mg.	2Mg.	2Mg.	2Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.
Size of Filter, Medium (See also, Table XXXII.)									$1\frac{1}{2}$ to $0\frac{3}{4}$ ins.				2 to 1 ins.				$2\frac{1}{2}$ to $1\frac{3}{4}$ ins.				$2\frac{1}{2}$ to $1\frac{1}{4}$ ins.				$2\frac{1}{2}$ to $1\frac{1}{4}$ ins.				

Trickling Filter 3, and Settling Tank, (Humus). All Depths.

Depth below surface of bed	4 ft.				6 ft.				7.25 ft.				8.50 ft.				10 ft.*				Humus Tank 9			
1915	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.	Jul.	Aug.	Sep.	Av.
Tot. susp. solids, p.p.m.	79	62	63	68	75	54	44	58	82	58	51	64	80	56	54	63	85	58	35	59	26	16	18	20
Vol. " "	56	45	48	50	51	37	32	40	56	40	37	44	55	38	40	44	59	40	27	42	21	12	14	16
Temperature, C.	23.3	22.0	24.8	23.4	23.2	21.6	24.4	23.1	23.0	21.5	24.3	22.9	23.0	21.3	23.7	22.7	22.6	21.2	23.6	22.5	22.4	21.3	24.1	22.6
Diss. ox. p.p.m.	2.6	2.2	1.6	2.1	2.3	3.4	3.1	2.9	3.2	3.9	3.2	3.4	3.4	4.3	4.0	3 9	4.1	5.3	4 8	4.7	1.4	1.9	1.9	1.7
" " % sat.	30	25	19	25	27	38	37	34	37	44	38	40	39	48	47	45	47	59	56	54	16	21	27	20
Rel. stability %	33	25	7	22	100	100	100	100	100	100	100	100	100	100	92	97	100	100	100	100	100	100	100	100
" " (paper-filt.)	83	54	20	52	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	.....	.....	.....	.....
Ox. demand, p.p.m.	57	59	113	76	36	36	46	39	42	37	65	48	38	35	51	41	33	36	35	35	13	11	20	15
" " (paper-filt.)	29	33	54	39	13	16	22	17	13	15	20	16	10	11	15	12	10	11	10	10	.....	.....	.....	.....
Nitrogen as nitrites	0.6	0.4	0.7	0.6	3.2	2.8	2.2	2.7	2.4	2.4	2.0	2.3	2.6	2.1	2.1	2.3	2.3	2.2	2.5	2.3	3.1	2.5	3.1	2.9
" " nitrates	0.5	1.0	1.7	1.1	7.2	7.0	10.2	8.8	11.1	8.0	10.9	10.0	11.6	9.4	12.1	11.0	12.0	10.4	14.5	12.3	10.7	9.0	11.0	10.2
Daily rate per acre	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	4Mg.	.....	.....	.....	.....

For Crude Sewage and Imhoff Tank Data see Table above.
Size of Filter Medium $2\frac{1}{2}$ to $1\frac{1}{4}$ inches.
Humus Tank with 10 ft. depth only.

which had passed these screens, was applied to the beds of Group A, beginning June 1, 1916, and this method of operation was continued to the middle of January, 1917, when, owing to the failure of the pump, it was necessary to shut down until March 1, when operation began, first on Imhoff tank effluent for a month, then on screen effluent for the rest of the year.

The results obtained from the application of Imhoff tank effluent, and from that of screened crude sewage, are given in sufficient detail to enable a comparison. See tables 27, 35, 36.

Experiments With Imhoff Tank Effluent on Trickling Filters

Analytical observations date from April 1, 1914. Previous to this the filters were undergoing a period of tuning up, and their mechanical operation was being studied.

When first put in service, all the filters were operated at the rate of 2,000,000 gallons per acre daily, which was continued during the time of preliminary trial. This rate was maintained on the filters of Group A from April 1, 1914, to October 1, 1914. The filters of Group B were operated at varying rates from two to five million gallons per acre daily.

On October 1, 1914, filters Nos. 2 and 3 were set operating at 4,000,000 gallons per acre daily; filters 1 and 4 remaining at 2,000,000. These rates were carried until the end of 1917. Filters 5 and 6 were operated from the spring of 1915 at the rate of 4,000,000 gallons per acre for the remainder of the experiments.

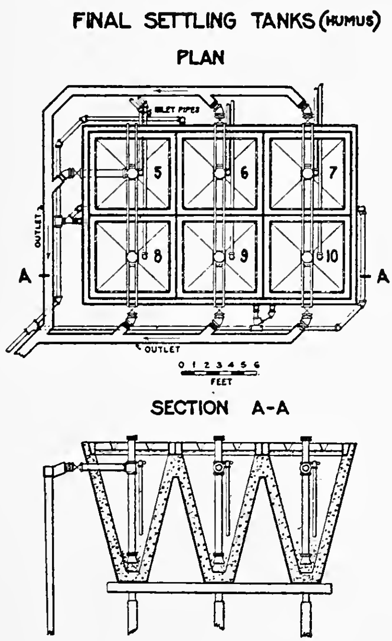

Fig. 24.

Final settling tanks proved to be essential in the treatment of the effluent from the trickling filters. The effluent carried very considerable quantities of floculent, but very readily settleable materials in suspension, also the remains of animal life from the beds, in the form of dead worms in masses, as well as living ones. The amount of suspensa carried by the filter effluent were at times surprising, when for any reason an unloading of films derived from the medium appeared. The sludge settled out in the settling tanks at times made all the difference between a putrescible and a non-putrescible effluent from the plant. This sludge was highly putrescible and very difficult to dry. It should be returned as a rule to primary tanks for full treatment.

The quantity of settlings removed by these tanks seemed to be about the same whether the sewage had passed an Imhoff tank or a fine screen before filtration, and to depend mostly if not altogether on filter conditions and phenomena.

A B C

Fig. 25. Trickling Filter Effluent.

The bottles are about 16 inches high and are stood against a sheet of white cardboard supporting a line of black.

A—Crude Sewage. Settleable solids about 200 P. P. M.

B—Imhoff Tank Effluent. 80% removal of settleable solids.

C—Unsettled Effluent from 7 ft. 3 in. depth of filter. Relation stability 99% to 100% average.

The settling tank following filter No.3 removed in 1 hour's retention, from October, 1914, to September, 1915, 62 per cent. of the solids in suspension in the filter effluent. The settling tank following filter No. 1, removed in 2 hours' retention 90 per cent of the solids, and the settling tank following filter No. 5 removed in 3 hours' retention 70 per cent. of the effluent suspensa. With these tanks in operation bacterial removal approximated 99 per cent. and the plant effluent was 100 per cent. stable.

Concluding Remarks

In concluding this account of his work, the writer feels as tho after much labor he had accomplished but little. At most, he has obtained some fragmentary information as to what tanks, screens and filters will, and especially what they *will not do;* but these are, after all, rather negative data. The knowledge derived from one plant can only be of partial and unbalanced character. Observations from many plants obtained in accordance with a definite system of investigation employed in each instance, or universally, would be of real value and would advance science to a higher plane. Unfortunately, there is not that uniformity now in practice which will give such a result. Much has been done to advance this object, however, especially by such institutions as the Massachusetts Institute of Technology, the American Public Health Association, and other agencies of progress that might be mentioned. The work of some of our consulting engineers has also been very fruitful along these lines. The books of Messrs. Metcalf and Eddy, and of George W. Fuller have accomplished much; but more is needed, especially in the way of co-operation among engineers and sanitarians, and more quiet, studious discussion among these men.

Looking at these problems from the standpoint of a mere municipal engineer, the writer has never felt and does not now feel satisfied with the present status of sewage disposal,—that necessary evil that must be compromised with—under the present state of our knowledge. As to tanks of all kinds, they are abominable to many, and so also are screens of all kinds. "It cannot be that these are the only possible methods of treating sewage"! Nor is the trickling filter a friend to all. As the pot calls the kettle black, so the ancient House of Tanks and the aspiring House of Screens belabor each other with bad names, out with the lot! "A plague on both your houses!' Give us something new and without fault. Possibly the future will produce such a method of sewage treatment that this age will seem the age of barbarism, and the following ideal of such a plant shall close this paper: It shall be a simple electrically operated machine, placed in a fine large hall, with potted palms at convenient places for decoration. The sewage will enter from below and will rise up thru the plant, being discharged, after treatment, a pure pellucid stream of water, cascading down to the nearby city reservoir. Meanwhile, from one side of the plant, in neatly done up bundles, will come forth automatically compressed fertilizer, containing nitrogen units enough to pay all expenses.

CONTENTS

TABLES